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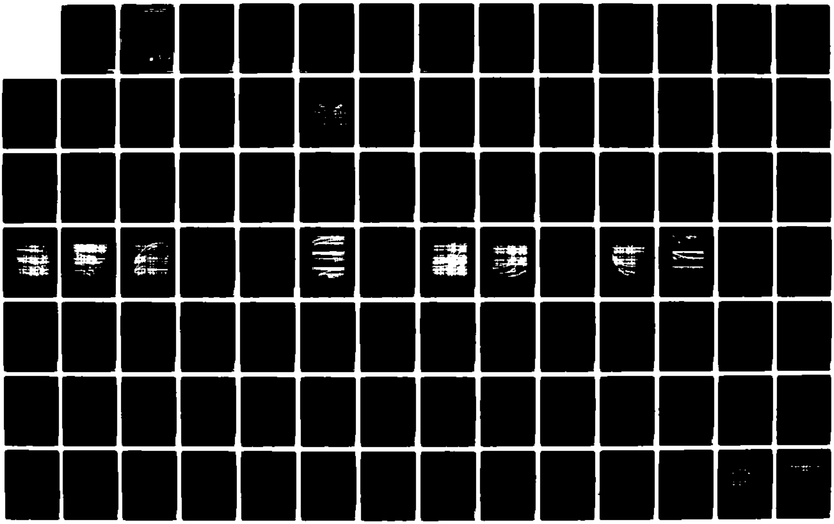

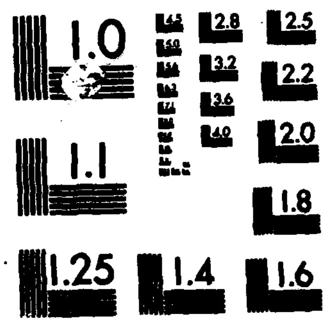
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The Logistics of Oil Spill Dispersant Application

Volume II: Application Techniques, Stockpiling, Dispersant Selection, Strategies

Transportation Systems Center
Cambridge MA 02142

November 1982
Final Report

U.S. Department of Transportation
United States Coast Guard

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16. Abstract

The use of chemicals for oil spill dispersal, while not presently widespread in the U.S., would have implications for the U.S. Coast Guard's Marine Environmental Protection program. This report explores the logistics of oil dispersant application by the U.S. Coast Guard.

Volume I: <u>Logistics-Related Properties of Oil Spill Dispersants</u>

Data were reviewed for the 13 dispersants for which data had been submitted to the EPA as of October 1979. Manufacturer's data and published test results were also examined and information summarized with regard to classification, handling and storage, application, availability and cost.

Volume II: <u>Application Techniques, Stockpiling, Dispersant Selection, Strategies</u>

Formulae and charts are developed for analyzing single and multiple-pass application; factors in stockpiling, and present inventories are examined; the factors in dispersant selection from Volume I are summarized. Six operational strategies, consisting of choices of vehicles, stockpiles and dispersant, are formulated and evaluated.

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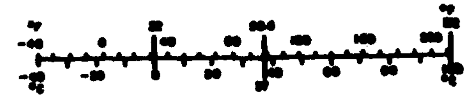
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

The use of chemicals for the dispersal of oil spilled on water has been the subject of discussion (and of disagreement) since their first major use in the Torrey Canyon disaster in 1967. The net adverse ecological effects produced by dispersants in that spill raised serious questions about their use. Although dispersant formulations have since been developed that are more effective and less toxic than those used on the Torrey Canyon spill, their use is not universally accepted. In the United States, in particular, a cautious approach has been taken; use of dispersants is governed by the National Oil and Hazardous Substances Pollution Contingency Plan, which requires that approval be obtained from the Regional Response Team before chemical dispersion is undertaken. This approval has been sought and employed in relatively few cases in the United States compared to other countries.

Despite their infrequent use at present in the United States, the implications of chemical dispersion of oil would be substantial for the US Coast Guard if it become common. Accordingly, the US Coast Guard Office of Marine Environment and Systems (USCG/G-W) requested the Transportation Systems Center to analyze the logistics of handling, stocking, transporting and applying of chemical oil dispersants. The study was carried out by the Transportation Systems Center Office of Air and Marine Systems (DOT/DTS-500) in Fiscal Year 1980.

The project was initiated under the sponsorship of CDR J. Valenti, USCG/GWEP, and completed under CDR. R. Rufe Jr. of the Pollution Response Branch, Environmental Response Division. Technical guidance and assistance were provided by LCDR W. Jurgens and CDR J. Paskowich of the US Coast Guard. Numerous Coast Guard personnel provided assistance and information, as did many individuals in the Environmental Protection Agency and industry.

The report is in two volumes. Volume I deals with the logistics properties of dispersants, and Volume II deals with their application.

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INTRODUCTION

Research and discussion concerning the use of chemicals for the treatment of oil spills has risen substantially in the last three years.[1] While it is still not clear that the use of dispersants in US waters will be expanded,[2] it must be assumed that their widespread use would have important impacts on the Coast Guard's Marine Environmental Response Program. These impacts would occur in the areas of operational procedures, programs, planning, funding, and effectiveness. In order to assess these impacts the Coast Guard has initiated a study of the logistic requirements of oil spill dispersal by chemicals. The first part of the study, covered in the Volume I, deals with the classification of dispersants,[3] storage and handling properties, characteristics, availability, and cost. This volume deals with techniques of dispersant application, the factors in dispersant stockpiling, selection of dispersants and the formulation of over-all strategies. In the final section of this volume the methods developed are synthesized into a set of recommendations for the Coast Guard in acquiring, stockpiling, transporting, and applying dispersants for oil spills in U.S. waters.

It must be noted that this study does not deal with the very important question of whether dispersants should be used in any given spill case. The decision to do so must be based on the judgment of the EPA member of the Regional Response Team, in consultation with appropriate state and local agencies, that their use would result in the least overall environmental damage,

[1] See, for example, the Introduction of Reference 1. The number of papers dealing with dispersants in the 1977 and 1979 Conferences on the Prevention and Control of Oil Spills was about double that in the 1973 and 1975 meetings.

[2] After their use in the Santa Barbara Spill in 1969, dispersants were not used under Annex X of the National Contingency plan until 1978 (dredge Pennsylvania) and again in 1979 (Sea Speed Arabia).

[3] Oil collecting agents and biological additives are excluded.

or interference with designated water use (National Contingency Plan, Annex X, 2003.1-1.3). This advice is binding on the On-Scene Coordinator (National Contingency Plan, 1510.36(3)). The intent of this study, rather, is to determine the Coast Guard logistics requirements stemming from such decisions, if and when they are made.

DISPERSANT APPLICATION TECHNIQUES

The application of a dispersant to the slicks resulting from an oil spill usually involves repeated round trips from the dispersant supply base to the spill area by aircraft or vessels specially outfitted to apply the dispersant. The speed and efficiency with which the operation is completed depends on several parameters, including the speed of the vehicles, the size and shape of the slicks, the distance from supply base to the spill, and the time required to reload the vehicles. It is important for planning purposes to estimate the time and cost of dispersing a given amount of spilled oil as a function of these parameters. Of special interest is the comparison of time and cost for aircraft as opposed to vessel.

Several analyses of dispersant application have been published. (References 1, 2, 3.) Hildebrand et al. treated a problem of concern to the Canadian Environmental Protection Service, namely, that of responding to a spill in the southern Beaufort Sea. Lindblom has developed extensive tables for several aircraft, and Steelman has analyzed both workboats and aircraft in two spill scenarios, using methods that were verified by actual experience at the IXTOC I blowout. The analysis to follow adapts the extensive work of these three sources to the particular requirements of the U.S. Coast Guard.

1. SINGLE PASS ANALYSIS

A single pass of a vehicle dispensing a chemical over a uniform slick may be described approximately by the equations

$$t = \frac{1}{10} V/A \tag{1}$$

$$a = 10{,}000\ te \tag{2}$$

$$d = \frac{1}{600}\ v\ w\ a \tag{3}$$

where

V = Volume of oil in slick, metric tons

A = Area of slick, hectares

t = Thickness of slick, millimeters

e = Effectiveness ratio, dispersant to oil

a = Areal density of dispersant, liters/hectare

w = Width of dispersant swath, meters

v = Vehicle speed, kilometers/hour

d = Dispersant dosage rate, liters/minute

If the volume of oil and slick area are not known, or if the slick can not be considered uniform, then the first two equations must be discarded and an estimate made directly of a, the desired areal density of dispersant. This will be necessary also when the effectiveness ratio, e, is not known. Values of a in the range 27. to 90. liters/hectare (3. to 10. USG/acre) have been used in tests by API/SC-PCO (Reference 4). Warren Spring Laboratories used values of 54. to 109. liters/hectare (5. to 10. gallons imperial/acre) (Reference 5).

The dispersant areal density, a, the vehicle speed, and the swath width are related to the dosage rate, d, by equation (3). Usually the dosage rate and vehicle speed are controlled during the pass so as to produce the desired areal density.

In general, it is desirable to operate at as high a dosage rate as is practical, since this will reduce the over-all mission time. Higher dosage rates, however, require either higher vehicle speeds, or greater swath widths, or both, as seen in (3), if the desired application areal density, a, is to be maintained. In vessel application the dosage rate is usually limited by the vessel's speed. In aircraft application the speed is high enough that the dosage rate is usually limited by the pumping rate, p, of the airborne equipment. For both vessel and aircraft, the maximum swath width is directly related to the vehicle size and this is always a limiting factor.

The relations (1), (2) and (3) are summarized in the chart in Figure 1. This chart may be used to plan a pass over a uniform oil slick by any of the commonly employed vessels or aircraft.

Example: A large harbour slick is to be dispersed by work-boat. The amount of oil is known to be 100 metric tons (about 30,000 gallons). The size is estimated to be about ln. mi. long and 0.6 n. mi. wide (22 million sq. ft. or 200 hectares). The dispersant effectiveness ratio is assumed to be 1:10 when employed on the crude involved. The work boat swath width is 20 meters, and its top speed is 20 knots or 37 km/hr. Its pumps can be adjusted to put out from 5 to 25 gallons/minute (19 to 95 liters/minute).

The chart in Figure 1 is entered at the lower right with the slick area; 200 hectares. One proceeds then horizontally to the left, reaching the diagonal line representing the (known) amount to be dispersed, 100 tons, and thence up vertically along the slick thickness line (read off at the top as .05 mm), to the diagonal line corresponding to the (known) effectiveness ratio, 1:10. The dashed line then goes horizontally to the left at the resultant areal density (50 liters/hectare) to the diagonal line for the swath width, 20 meters. The dashed line then descends to the lower left quadrant to a diagonal line representing the pumping or dosage rate. If a pumping rate of 50 liters/minute is selected, then it is seen that the work boat must travel at 30 kilometers/hour (16 knots). Alternately, one may select the vessel speed (say, 15 kilometers/hour or 8.1 knots) and from the intersection of the corresponding horizontal line with the vertical dashed line, determine that a dosage rate of 15 liters/minute would be required.

Since the dispersant to oil ratio is taken to be 1:10 for full dispersion, 10 tons of dispersant will be required to treat the 100 tons of oil. At 15 liters/minute (3.96 US gallons or .0132 tons/minute) it will take about 6.3 vessel-hours, of spraying. Allowing a maneuvering efficiency of 0.25 gives on-scene operating times of 50.4 vessel-hours or 25.2 vessel-hours, depending on the dosage rate selected.

Note that spills of larger area and volume than shown in Figure 1 may be accommodated by multiplying by 10 the numbers for slick area and spill volume shown in the lower right quadrant.

2. MULTIPLE PASS ANALYSIS

Most oil spills must be treated by several passes of the vehicle, for several reasons. First is the geometry of the slick or slicks. This geometry is seldom suited to a single pass, so

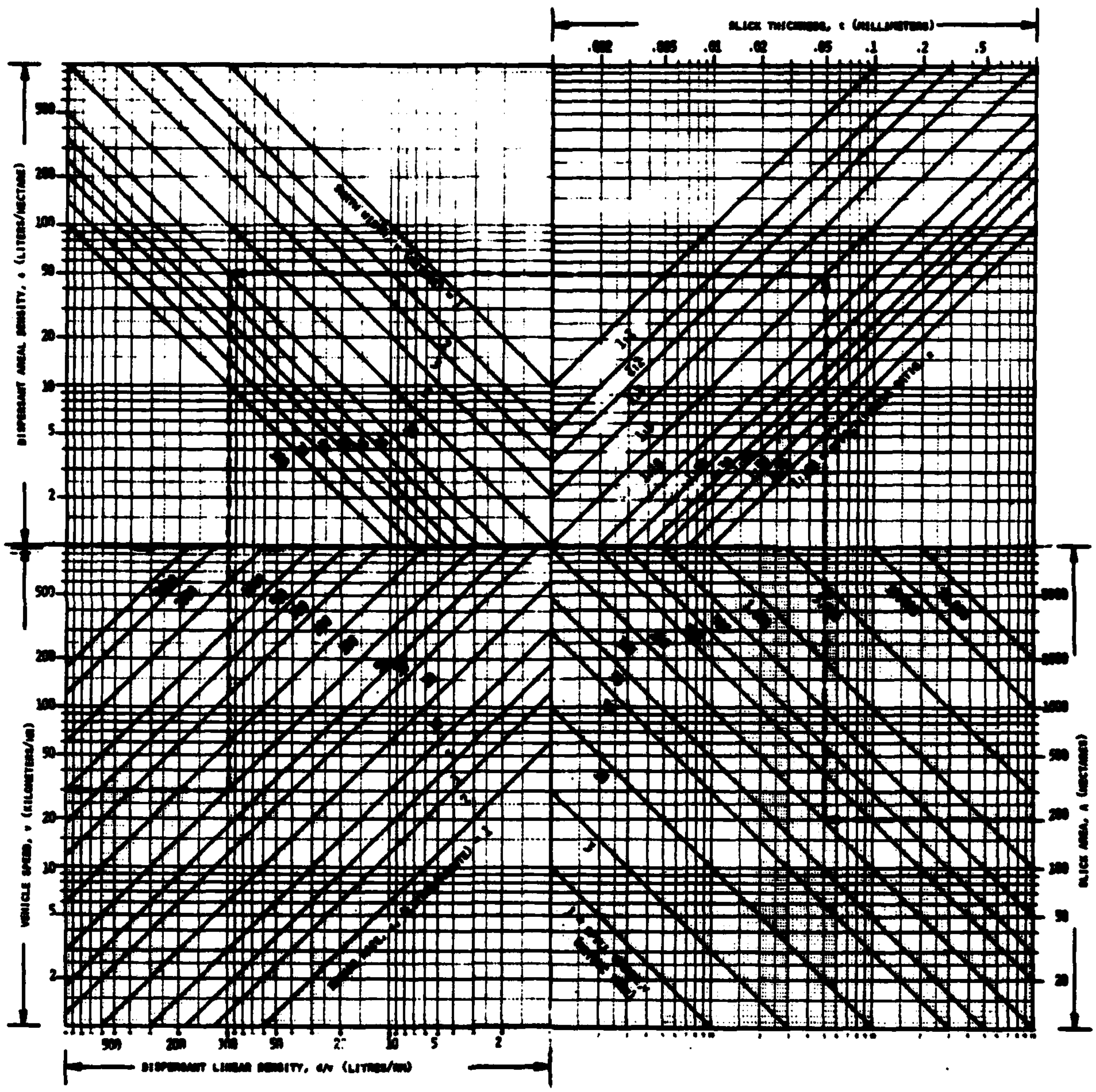


FIGURE 1. DIAGRAM FOR PLANNING A SINGLE SPRAY PASS OVER A UNIFORM SLICK

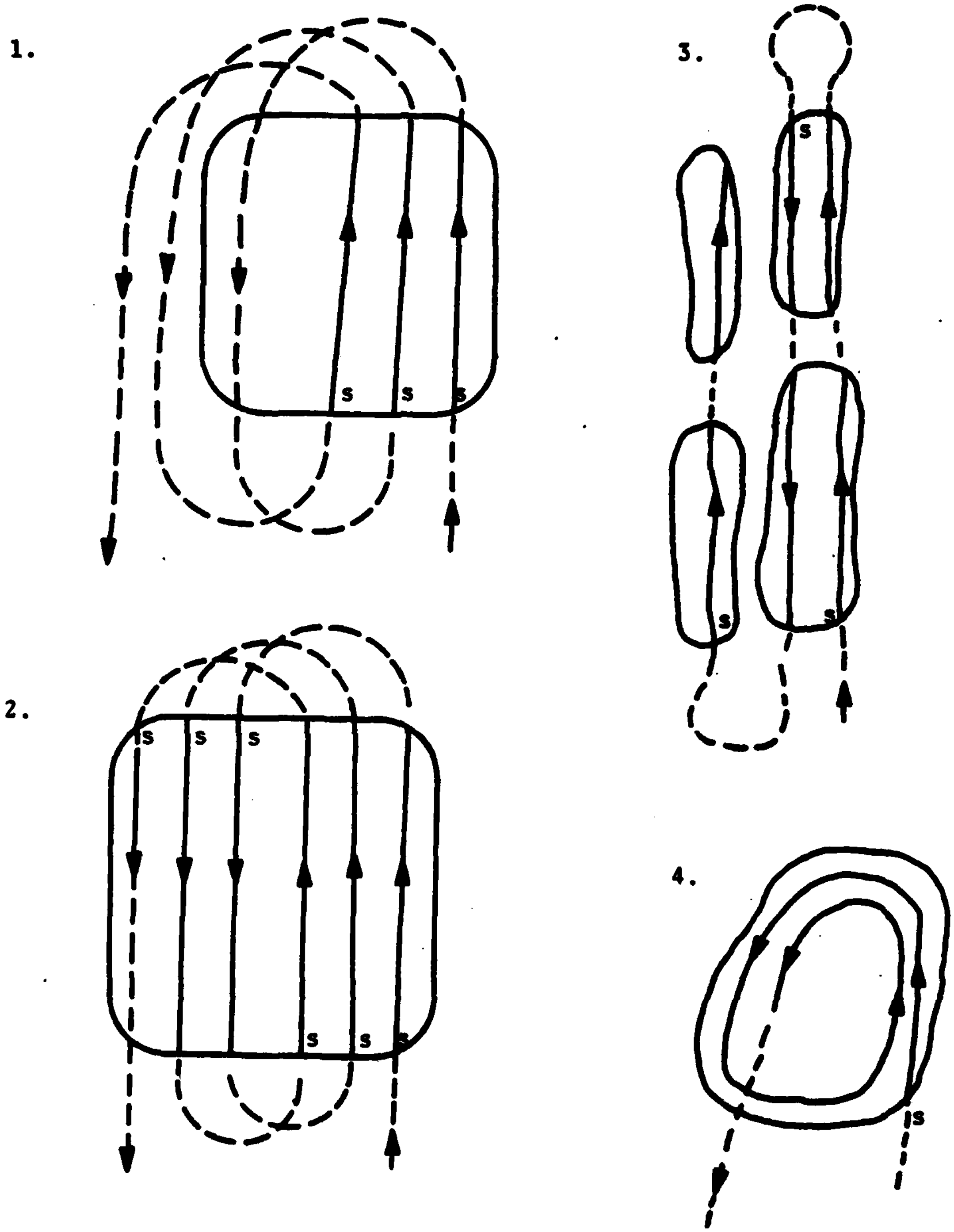
that a series of passes must be devised to make up a spray pattern that fits the particular slick geometry and spraying priorities of the spill. Secondly, the vehicle must return to its operations base for restocking dispersant and fuel. Finally, since spraying can be conducted effectively only in daylight, several days of operation may have to be allowed for. The objective here is to determine the effect of these three restrictions on the total time required to treat a given spill, or, what is equivalent, on the total amount of oil that can be treated in a given time.

2.1 Effect of Spray Pattern

A spray pattern comprises a series of passes over one or more slicks by the spraying vehicle. The time required to execute the pattern depends on the total area sprayed, the speed of the vehicle(s) in spraying, turning, and repositioning, the turning radius, the mean slick length, slick continuity, and the swath width.

Figure 2 illustrates five spray patterns. The same patterns also apply if the sections of slick shown in this figure are discontinuous, as shown explicitly in pattern 3. In that case, the spray would be turned off as the vehicle traverses segments of open water, but the vehicle would not change speed or course. The first two patterns are for aircraft application, the latter two are for vessel application. Pattern 3 may be adapted for either. These patterns are related to these for SAR (App. I).

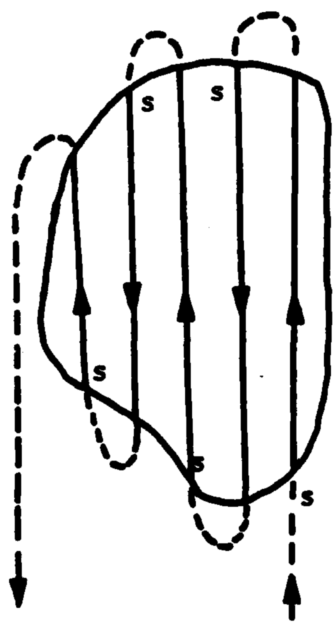
Aircraft patterns are more restricted than vessel patterns because they require a much larger minimum turn radius (typical values being 0.5 to 1.0 n.mi.). Also, aircraft patterns must take account of the wind. Crosswind spraying is generally found to lead to a less uniform cover of dispersant. Spraying into or with the wind leads to more uniform results, but the airspeed must be adjusted so as to give the proper ground speed, i.e., the parameter v in the single pass analysis is ground speed. Pattern 1 provides spray runs in one direction only, which direction can be chosen to be parallel or anti-parallel to the wind vector. Pattern 2 provides runs both with and against the wind. Pattern 2 is more dif-



s = Start of pass ——— spray on - - - - - spray off

FIGURE 2. TYPICAL SPRAY PATTERNS

5.



s = Start of pass

FIGURE 2. TYPICAL SPRAY PATTERNS (CONTINUED)

cult to execute than Pattern 1 because the airspeed must be adjusted to different values on the upwind and downwind legs. Pattern 3 differs from 2 only in that the slick, and the spray trail, are discontinuous. However, if executed by an aircraft, the turn in Pattern 3 requires a total curvature in excess of 360 degrees. This would take over 2 minutes for large aircraft.

For helicopters and workboats, turning radius R is small, which leads to greater pattern efficiencies. Also, workboat spraying accuracy is relatively unaffected by wind direction, so that the less efficient patterns such as 1. in Figure 2 are unnecessary for vessels. But because of their lower speeds, it is expected that vessels will have higher overall pattern execution times than aircraft.

In the case of both aircraft and vessels it has been found that a spotter aircraft is essential to avoid low pattern efficiencies. It will be assumed throughout this analysis that all patterns are executed under the direction of a spotter aircraft so that no time is spent unnecessarily between passes.

The total time, T_p, spent in executing a spray pattern comprises four terms:

$$T_p = T_s + T_x + T_t + T_r \tag{4}$$

where

T_s = time spent spraying in the pattern, hours

T_x = time in spray pass, between patches of oil, without spraying, hours

T_t = time spent turning, hours

T_r = time spent repositioning to start of next pass, hours.

These terms are given for the six patterns of Figure 2 in Table 1. It can be seen from Figure 3 and Note (2) of the table that long narrow spray patterns require fewer passes to complete, and hence incur less of a penalty in turning time, T_t. Only pattern 1 calls for a repositioning time, T_r.

TABLE 1. TERMS IN EQUATION (4) FOR TOTAL TIME IN SPRAY PATTERN

Pattern/Vehicle	T_s	T_x	T_t	T_r
1/Fixed Wing	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(2\pi R+w')}{v_t}$	$\frac{A_p}{w}\frac{10}{v_r}+\frac{L_p}{v_r}$
2/Fixed Wing	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(\pi R+w')}{v_t}$	
3/Fixed Wing, Helicopter, or Vessel	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(\pi R+4\phi R)}{v_t}$	
4/Helicopter or Vessel	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$		
5/Helicopter or Vessel	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(\pi R+4\phi R)}{v_t}$	
6/Several Vessels	$\frac{1}{n_V}\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{n_V w}\frac{10}{v_x}$		

A_s = area of slick within the pattern, hectares

w = swath width, meters

v_s = vehicle speed while spraying, kilometers/hr

A_p = area of pattern, hectares (See Figure II-3)

v_x = vehicle speed in pass, not spraying, kilometers/hr

R = vehicle turning radius, kilometers

v_r = vehicle speed while repositioning to next pass, kilometers/hr

L_p = length of spray pattern, kilometers (See Figure 3)

v_t = vehicle speed in turning, kilometers/hr

w' = swath width, kilometers

- continued on next page -

TABLE 1. TERMS IN EQUATION (4) FOR TOTAL TIME IN A SPRAY PATTERN (CONTINUED)

n_p = number of passes in pattern

n_V = number of vessels in pattern 6.

$\cos\phi = (1 + w'/(2R))/2, \; w' \leq 2R$

Notes: (1) T_s, T_x, T_t, T_r in hours

(2) $n_p = W_p \, 1000/w$

where W_p is pattern width, Figure 3.

(3) $\bar{L}_p$ = mean spray pass length, kilometers

$= \frac{A_p/W_p}{100}$

(4) $R = v^2/g \tan\theta$ for aircraft

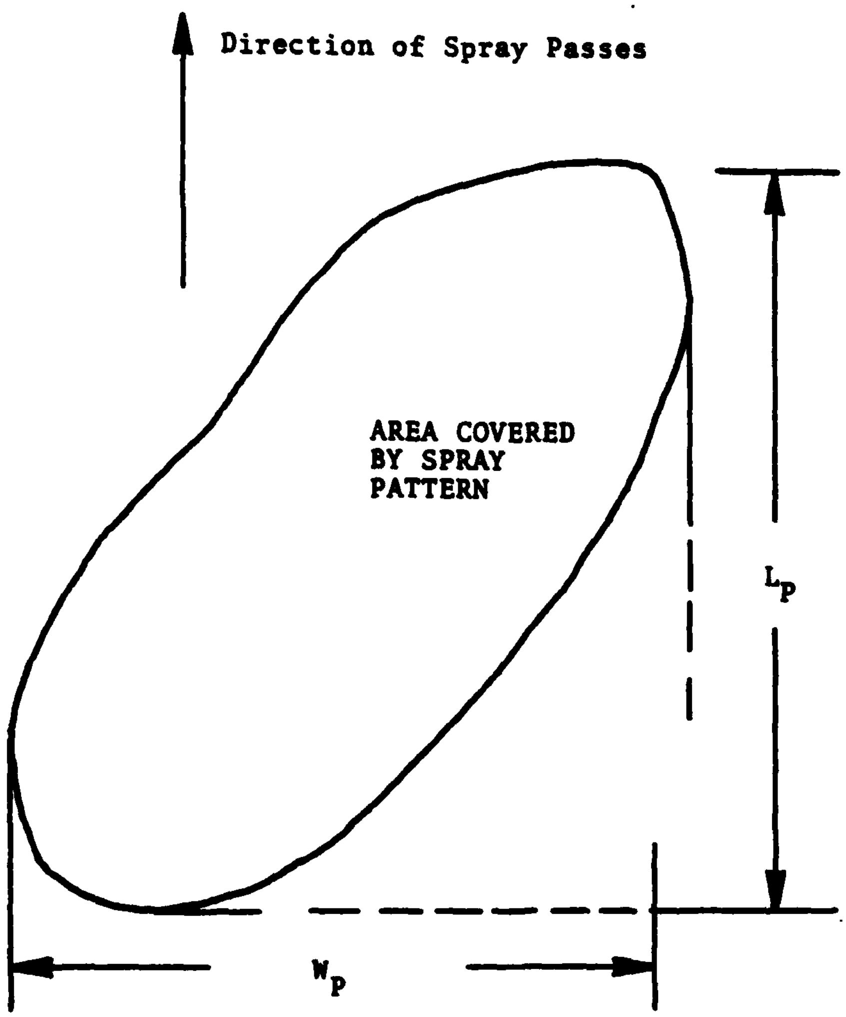
where v is groundspeed in turning, v_t

θ is bank angle

g is acceleration of gravity, 980 cm/sec/sec

(5) α = fraction of spray pattern covered by slicks

$= A_s/A_p$



A_p = area covered by spray pattern
A_s = area of slick within spray pattern

FIGURE 3. DIMENSIONS OF AREA COVERED BY SPRAY PATTERN

It is of interest to calculate T_p/A_s, the pattern time per unit area of slick, within the pattern, for typical patterns, vehicles, and slick geometries. This is done in Table 2. The vehicles chosen are the DC-4, Piper Pawnee, Bell 206B, and a 37 meter workboat. A 30° bank angle is assumed for the aircraft turns, and a 75 meter radius turn for the workboat. It is assumed that the pattern is a long rectangle, lying parallel to the direction of the vehicle pass. It is also assumed that $\alpha = 1$, i.e., no open spaces in the slick, so that pattern area is the same as the treated slick area:

$$\frac{A_p}{100} = \frac{A_s}{100} = W_p L_p = \frac{wn_p}{1000} L_p$$

The results of Table 2 show that the DC-4 is an order of magnitude faster in completing patterns 1, 2, 3 and 5 than are the Piper Pawnee or Bell 206B. The Piper Pawnee is about twice as fast as the Bell 206B on patterns 1 and 2 but on patterns 3 and 5 it is faster than the Bell 206B only for slick lengths greater than .48 km. The Pawnee is about twice as fast to execute patterns 3, 4 and 5 as is the workboat. It should be noted that the Pawnee cannot execute pattern 4 on small slicks, but a workboat can do so.

The pattern execution times given by Equation (4) and Table 1 are expressed in terms of the slick area A_s being treated, as well as pattern and vehicle parameters. The slick area that can be covered by the pattern is usually determined by the vehicle's dispersant payload, P, and the areal density, a, obtained from single-pass considerations (Figure 1):

$$P = a\ A_s\ \text{(liters)} \qquad (5)$$

Equivalently, the payload may be related to vehicle speed, dosage rate and swath width:

$$P = 600d\ A_s/(v_s w) \qquad (6)$$

where d is in liters/minute and P is in liters. Either (5) or (6) serves to determine A_s.

TABLE 2. PATTERN TIME PER UNIT AREA OF SLICK FOR TYPICAL VEHICLES AND PATTERNS

	T_p/A_p (hours/hectare)
Pattern #1	
DC-4	$.00142 + .0027/L_p + .000034/W_p$
Piper Pawnee	$.00950 + .010/L_p + .000067/W_p$
Bell 206B	$.01880 + .011/L_p + .00010/W_p$
Pattern #2	
DC-4	$.00074 + .0014/L_p$
Piper Pawnee	$.00512 + .0050/L_p$
Bell 206B	$.01100 + .0059/L_p$
Patterns #3, #5	
DC-4	$.00074 + .0031/L_p$
Piper Pawnee	$.00512 + .0115/L_p$
Bell 206B	$.01100 + .0087/L_p$
Workboat	$.02800 + .0219/L_p$
Pattern #4	
Bell 206B	.0110
WorkBoat	.0278
Pattern #6	$.0278/n_V$

Data Employed to calculate T_p/A_p from formulas of Table 1:

Vehicle	$\frac{w}{m}$	$\frac{v_s}{km/h}$	$\frac{R}{km}$	$\frac{v_r}{km/h}$	$\frac{v_t}{km/h}$
DC-4	49	277	1.18	294	277
Piper Pawnee	15	130	.31	150	130
Bell 206B	16	56	.043	80	16
Workboat	20	18	.075	-	12

2.2 Effect of Round Trips from Operations Base

Unless the slick can be completely treated by one payload of dispersant, the vehicle must return to its operations base, reload fuel and dispersant, and then start on another sortie. The time for a complete round trip depends on dispersant loading time or vehicle refueling time, travel time to and from the next pattern, as well as pattern execution time:

$$T_R = T_F + 2\,T_T + T_P$$

where

T_R = total round-trip time, hours

T_F = time to refill dispersant tanks, T_{FD}, or refill fuel tanks, T_{FF}, hours

T_T = travel time to and from pattern, hours

T_P = pattern execution time, hours.

For most vehicles, fuel refilling takes longer but is required less frequently than dispersant refilling, so that T_F will be dispersant refurbishment time for most round trips. Maintenance is assumed to be accomplished during refilling time or at night when dispersant operations are suspended. The time T_F must also allow for landing and take-off or docking and departing. Crew change and vehicle inspection are assumed to be accomplished during refuelling or refilling of dispersant. The number of round-trips that can be accomplished on one fuel load depends on the distance from base to spray pattern and the time in the spray pattern.

The travel time T_T is related to the distance D from operations base to spray pattern by

$$T_T = D/v_T$$

where

v_T = vehicle speed in transit, kilometers/hr

D = distance from operations base to spray pattern, kilometers

Table 3 lists the operating parameters for several vehicles. These parameters affect the single pass operations discussed previously, round-trip operations, and daily operations to be discussed next.

2.3 Effect of Daily Operations

It is common to allow a 10-hour day for dispersant operations, resulting in an integral number of sorties per day for each vehicle. Early morning and late evening on clear days are hampered by a low sun angle, which makes it more difficult to detect the boundaries of the slick from the spotter aircraft. Nevertheless, these hours are still useful for transit from operations base to spill.

For each aircraft there is a trade-off between dispersant payload and maximum value of D. The larger the payload, including tanks, the less fuel can be loaded, and the shorter the range. Fuel consumption depends on air speed, altitude and payload. The total fuel consumed in a round-trip is C_F.

$$C_F = c_T T_T + c_s T_s + c_t T_t + c_r T_r + c_s T_x$$

where c_T, c_s, c_t, c_r are fuel consumption rates in liters/hour for transit, spraying, turning and repositioning. The total C_F is divided into the useable fuel load, and the quotient rounded down to the next integer, to determine the maximum number of round trips between refuelings. The useable fuel load equals the maximum gross take-off weight minus aircraft operating weight, fuel reserve, payload, and crew weight.

It is common for medium and large workboats to carry enough fuel for several days. Many small workboats can carry enough fuel for at least one day's operation. Therefore most vessels have $T_F = T_{FD}$ on all round-trips, i.e, refurbishment time is determined by dispersant refill time rather than refueling time, because refueling can take place overnight.

TABLE 3. TYPICAL OPERATING PARAMETERS FOR AIRCRAFT AND VESSELS IN DISPERSANT APPLICATIONS

			DC-6B
P	Maximum payload	liters	13250
p	Max pumping rate	liters/min	2450-2850
T_{FD}	Time to fill, (1) dispersant	hrs	.25-.33
T_{FF}	Time to fill, (2) fuel and dispersant	hrs	.40-.50
v_s	Speed while spraying	km/hr	260-295
v_T	Speed in transit	km/hr	390
v_t	Speed while turning	km/hr	260
v_r	Speed while repositioning	km/hr	325
R	Min turn radius	km	.92
w	Swath width, max	meters	55 (4)
T_D	spray time per load (3)	min	4.6-5.4

(1) Total turn-around time, refill dispersant but not fuel

(2) Total turn-around time, refill dispersant and fuel

(3) Equal to P/p.

(4) Average of 7 runs at 50 ft. altitude or less, nozzles 90° aft; Reference 6.

TABLE 3. TYPICAL OPERATING PARAMETERS FOR AIRCRAFT AND VESSELS IN DISPERSANT APPLICATIONS (CONT.)

	DC-4	CL-215	Pawnee	HH3
P	9460	5300	375-560	1500
p	1980-2270	1500	300-340	150
T_{FD}	.25-.33	.25-.33	.16-.25	.25
T_{FF}	.40-.50	.40-.50	.33-.50	20
v_s	260-295	195-240	110-150	65.
v_T	350	300	150	
v_t	260	195	110	0-65.
v_r	295	240	150	
R	.92	.52	.17	0.-.058
w	55 (4)	35	20	16
T_D	4.2-5.0	3.5	1.1-1.9	10.

	Bell 206B	Large WB	Medium WB	Small WB
P	172	38000.	7500	756
p	150	95	32	25
T_{FD}	.25	2.0	1.0	0.5
T_{FF}	.25	3.0	1.5	1.0
v_s	65.	12.0	7.0	7.0
v_T	160	22.	14.0	12.0
v_t	0-65.	12.0	7.0	7.0
v_r	160.	22.0	14.0	12.0
R	0.-.058	.075	.035	.020
w	38	20	7	3
T_D	1.1	400.	234.	30.

3. PARAMETRIC PERFORMANCE ANALYSIS

The purpose of this analysis is to guide the selection of an appropriate spray vehicle for a given dispersant operation. The selection is presumed to be made on the basis of one or more measures of performance, such as cost or time to disperse the slicks. The value of these measures for each vehicle depends on numerous parameters, only some of which can be quantified, and even fewer of which are normally under the control of the personnel conducting the operation. The most influential of those parameters are the size of the pattern of slicks, its distance from the vehicle operations base, mean slick thickness, and dispersant/oil ratio required for complete dispersal. The analysis compares performance measures for different application vehicles as functions of these parameters.

3.1 Performance Measures

The objectives of an oil dispersal operation are usually to

- o maximize the amount of oil dispersed,
- o minimize the time required to disperse it,
- o minimize the cost of the operation.

These objectives are normally in conflict; the more oil that is dispersed, the greater the time and money required. Selecting an application technique must be a trade-off among these conflicting objectives. In order to simplify the selection certain normalized performance measures may be calculated. They are:

- o Application rate (liters of dispersant applied per 10-hour day per vehicle)
- o Normalized cost (dollars per liter of dispersant applied)

The application rate is a useful performance measure because it can be used to relate the number of vehicles required to the amount of dispersant applied. Similarly, the normalized cost can be used to determine the total cost of applying a given amount of dispersant. Both measures are stated in terms of amount of

dispersant applied, rather than amount of oil treated. The latter depends on the effectiveness ratio, a highly variable quantity that is influenced by many factors other than the application vehicle. Estimation of the effectiveness ratio to be expected from a particular combination of dispersant, oil type and condition, temperature, agitation level, and application technique will be discussed in subsequent parts of this report.

3.2 Parameters Affecting Performance

The performance measures above are influenced by several variables, only some of which are taken into account here. Of those that are not here quantified, one has:

(1) Availability: This includes not only availability of a sufficent number of vehicles, but also of adequate crews and support equipment and fuel, as well as the proximity of a suitable operations base.

(2) Response Time: This is the time required to assemble the vehicles, crews, and support equipment at the operations base and prepare them for the mission.

(3) Suitability for selected dispersant: The application vehicle selection must be coordinated with the selection of dispersant; some dispersants require sea-water eduction systems, (not practical for aerial use) others require agitation. The suitability of a dispersant to a particular application method, moreover, cannot be inferred from its type (i.e., hydrocarbon-based, aqueous-based, or concentrate), but must be determined for each product separately.

(4) Safety of vehicles and crews: Small work boats are unsuitable for operation offshore under severe weather conditions. Large fixed wing aircraft cannot be safely operated at low levels near shoreline obstructions. Other conditions may preclude certain vehicles from use.

The major variables that have been considered in the analysis are:

- o Distance, D, from operations base to closest edge of slick pattern.
- o Length, L_p, of slick pattern, as shown in Figure 3.
- o Areal density, a, of dispersant, measured as volume of dispersant per unit area of slick.
- o Slick/Pattern ratio, S/P, equal to the fraction of the pattern area covered by oil slicks.

The first three of these variables have been treated parametrically, i.e., over a range of values, in order to determine how they affect the performance measures for each vehicle. The last has been fixed at a value of 0.5 in order to simplify the analysis.

In addition to the major variables above, values were selected for a large number of vehicle-specific variables. The specific values selected are shown in Tables 4A and 4B. It will be seen in that table that Pattern #1 was employed for the fixed wing aircraft and Pattern #3 for all other vehicles. These are conservative assumptions in both cases; fixed-wing aircraft might use Pattern #2, which is more efficient, and Patterns #4 or #6 might be more efficiently employed for the other vehicles. The effect of the assumed patterns is to underestimate the performance measures in all cases.

It was assumed in the calculation that the areal density of dispersant is achieved either at maximum pumping rate or at maximun spraying speed, depending on which is the controlling factor. The costs include fuel and crew, but do not include retainer fees, the cost of the dispersant itself, the cost of transport to the operations base, training costs (in the use of the HH3), or costs of spotter aircraft or vessels. The cost data are current as of 1979 and must be adjusted for inflation and fuel cost acceleration if they are applied to subsequent years.

TABLE 4A. VEHICLE-SPECIFIC VALUES EMPLOYED TO CALCULATE PERFORMANCE MEASURES

Variable Name	Units	DC-6	DC-4	CL215	Pawnee
Pattern Number	Figure 2	1	1	1	1
Dispersant payload	liters	13,250	9,460	5,300	560
Max pumping rate	liters/minute	2,850	2,270	1,500	340
Dispersant refill time	hours	.29	.29	.29	.205
Fuel refill time	hours	.45	.45	.45	.415
Operating time per refuelling	hours	5.5	5.5	4.0	2.5
Swath width	meters	55	55	35	20
Turning radius	kilometers	.92	.92	.52	.17
Spraying speed	km/hour	278	278	218	130
Transit speed	km/hour	390	350	300	150
Turning speed	km/hour	260	260	195	110
Repositioning speed	km/hour	325	295	240	150

TABLE 4A. VEHICLE-SPECIFIC VALUES EMPLOYED TO CALCULATE PERFORMANCE MEASURES (CONT.)

Variable Name	Units	HH3	B206B	MWB	SWB
Pattern Number	Figure 2	3	3	3	3
Dispersant payload	liters	1,360	172	7,500	756
Max pumping rate	liters/minute	150	150	32	25
Dispersant refill time	hours	.25	.25	1.0	0.5
Fuel refill time	hours	.33	.25	1.5	1.0
Operating time per refuelling	hours	3.8	2.15	160	16
Swath width	meters	29	38	7	3
Turning radius	kilometers	.29	.29	.035	.02
Spraying speed	km/hour	65	65	12	8
Transit speed	km/hour	96	160	14	12
Turning speed	km/hour	33	33	7	7
Repositioning speed	km/hour	96	160	14	12

TABLE 4B. VEHICLE SPECIFIC OPERATING COSTS

Vehicle Type	Operating Cost	Retainer Cost	Fuel Consumption	Data Source
DC-6B	$1650/hr	$3800/day	(1)	a.
DC-4	1200/hr	120K/yr	(1)	b.
CL215	1560/hr	-	204.USG/hr	c.
Pawnee	400/hr	100/hr*	(1)	a.
HH3	500/hr	0.	(1)	d.
206B	600/hr	150/hr	(1)	e.
LWB	4000/day	-	(1)	a.
MWB	2000/day	-	(1)	a.
SWB	900/day*	-	(1)	

(1) Cost included in Operating Cost.

Data Sources For Table 4B

a. Steelman, B.L., "Oil Spill Dispersant Application: A Time and Cost Analysis," Oil and Hazardous Material Spills: Prevention - Control - Cleanup - Recovery - Disposal, published by Information Transfer Inc., 9300 Columbia Boulevard, Silver Spring, MD 20910. (1979)

b. Cormack, D. and H. Parker, "The Use of Aircraft for the Clearance of Oil Spills at Sea," in Proceedings of the 1979 Oil Spill Conference, published by American Petroleum Institute, 2101 L St., N.W., Washington, D.C. 20037.

c. Hildebrand, P.B., A.A. Allen, and C.W. Ross, "The Feasibility of Oil Spill Dispersant Application in the Southern Beaufort Sea," Canadian Environmental Protection Service, EPS-3-EC-77-16, September, 1977.

d. Unofficial Estimate by US Coast Guard Office of Operations, G-OSR-2.

e. Approximate cost provided by Island Helicopter, Inc., Garden City, N.Y.

*. Estimate based on industry sources.

3.3 Results

The results of the calculation are shown in Figures 4 through 11.

Application Rate (Figures 4-7): The application rate in liters of dispersant per day is shown as a function of distance D from base to slick pattern in Figure 4 (pattern length = 0.6 km) and in Figure 5 (pattern length = 4.0 km). In both figures it can be seen that the vehicles fall roughly into three classes: large (fixed-wing) aircraft, small aircraft, workboats. The application rates differ between large and small aircraft by a factor of about 5.0; between small aircraft and boats by a factor of about 10.0. Further, it can be seen that the three classes have different ranges (i.e., the base-to-slick distance at which the application rate drops to one-half of its maximum value varies substantially). This distance, which may be termed the "half-range" is shown in Table 5. The large aircraft have half-ranges of 200-300 km, the small aircraft have half-ranges of 30-50 km, and the boats have half-distances of 20-30 km.

An important parameter in performance is L_p, pattern size; i.e., mean length of pass over the pattern. Roughly, this parameter corresponds to spill size; larger spills cover a larger area and usually have larger dimension, L_p. Figure 6 shows that, generally, the larger the mean pattern dimension L_p, the more effective the performance of the vehicle. (The one exception, the Pawnee, is due to its limited dispersant capacity relative to other fixed-wing aircraft operating in Pattern #1). In general, it is seen that the large aircraft and the HH3 operate more effectively for mean pass lengths above the 1.5 - 2.0 km range, while the other vehicles operate best with L_p above 0.2 - 0.5 km. Table 6 shows for each vehicle the minimum mean pass length for which it can achieve at least

TABLE 5. HALF-DISTANCES FOR VARIOUS DISPERSANT APPLICATION VEHICLES

Vehicle	Class	Half-range (km)	
		$L_p = 0.6$	$L_p = 4.0$
DC6	large aircraft	360	280
DC4	large aircraft	300	175
CL215	large aircraft	220	150
Average	large aircraft	293	201
Pawnee	small aircraft	42	32
HH3	small aircraft	70	42
B206	small aircraft	38	21
Average	small aircraft	50	32
MWB	medium boat	28	32
SWB	small boat	20	19
Average	boats	24	26

PATTERN LENGTH = 0.6 KM
AREAL DENSITY = 45 LITERS/HECTARE
SLICK/PATTERN RATIO = 0.5

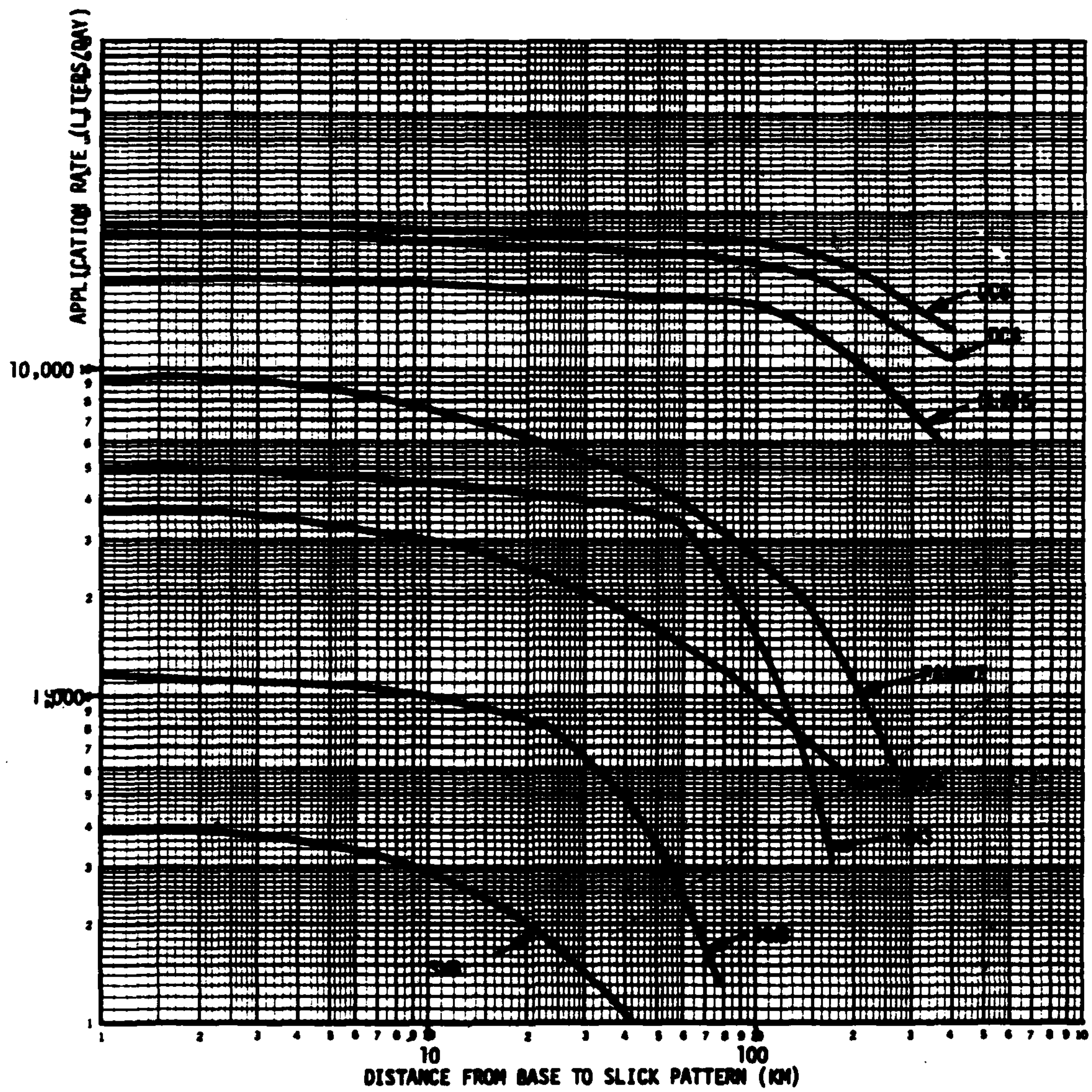


FIGURE 4. APPLICATION RATE VS DISTANCE TO SLICK FOR PATTERN LENGTH = 0.6 KM

PATTERN LENGTH = 4.0 KM
AREAL DENSITY = 45 LITERS/HECTARE
SLICK/PATTERN RATIO = 0.5

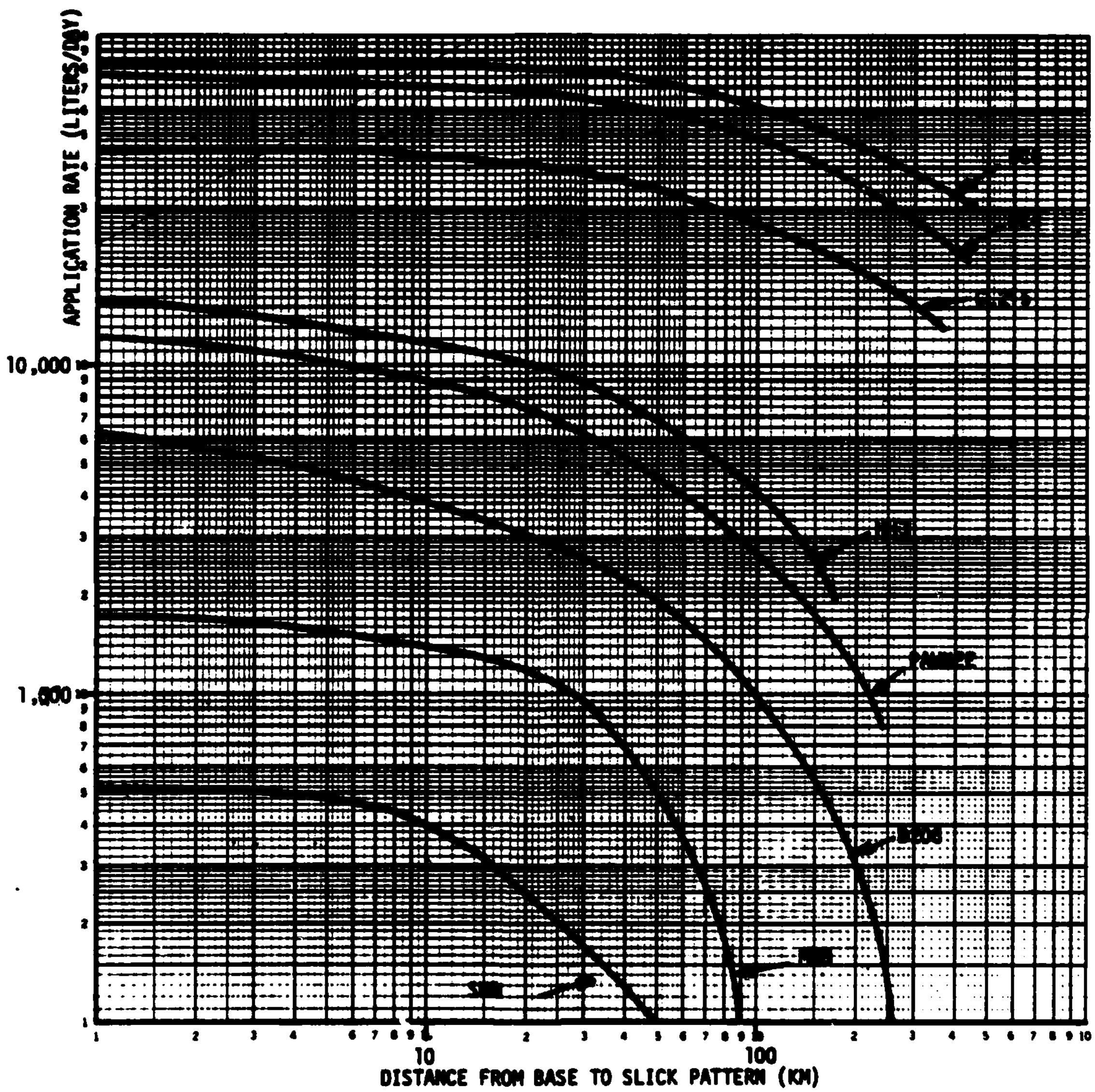


FIGURE 5. APPLICATION RATE VS DISTANCE TO SLICK FOR PATTERN LENGTH = 4.0 KM

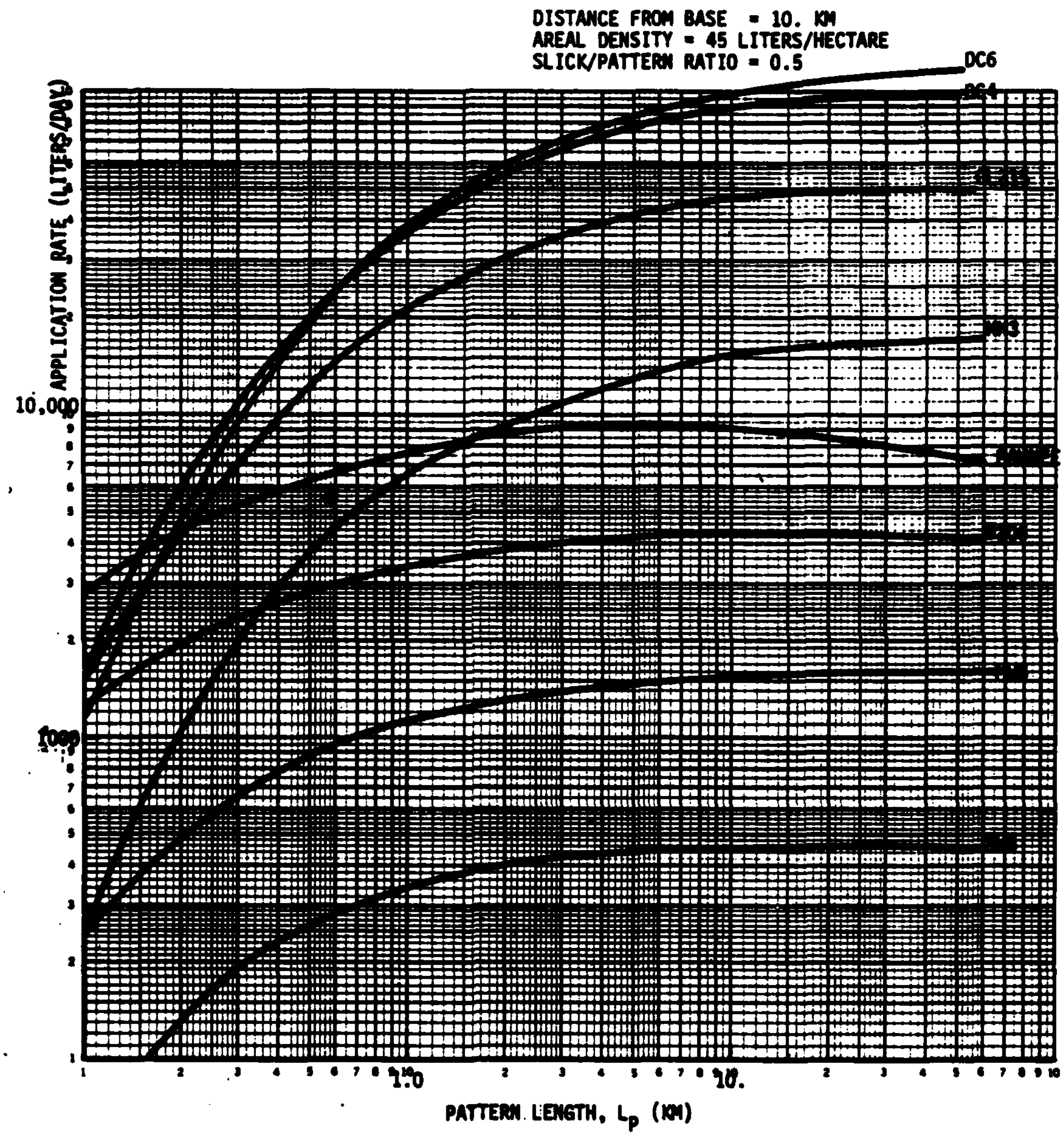


FIGURE 6. APPLICATION RATE VS DISTANCE TO SLICK
FOR PATTERN LENGTH = 10. KM

TABLE 6. MINIMUM PASS LENGTHS FOR ONE-HALF OF MAXIMUM APPLICATION RATE

Vehicle Type	Minimum Mean Pass Length, L_p for 50 % of Maximum Application Rate
DC6	2.0 km
DC4	2.4
CL215	1.6
HH3	1.7
Pawnee	0.21
B206	0.23
MWB	0.40
SWB	0.40

NB Areal density = 45 liters/hectare
slick/pattern ratio = 0.5

one half of its full application rate. It is doubtful if any vehicle can operate effectively for slick pass lengths under 0.2 km under the speed assumptions made in the calculation. The speed assumptions can be lifted for the workboats and the two helicopters, but not for the fixed wing aircraft.

The final parameter varied in the calculation of application rate is areal density (Figure 7). Application rate increases, in general, with areal density of dispersant, because less time is required to apply a given amount of dispersant. The increase in daily application, however, is less than the increase in dosage, i.e., doubling the dosage does not double the total amount applied in a day. The reason for this is that the higher dosage rates deplete the vehicle's dispersant supply more rapidly and a greater fraction of the day must be spent in returning to the operations base for refilling dispersant.

The areal density of dispersant is usually selected arbitrarily if the effectiveness ratio is not known (the usual situation). It has been found that 45-90 liters/hectare (5-10 gallons/acre) is a convenient nominal dosage. The application is repeated if the first application does not result in good dispersion of the slick. This procedure is not as inefficient as one might estimate on a naive basis, as the following example shows:

Example: Suppose a slick of 600,000 liters of oil is to be dispersed with a product having a 1:20 effectiveness ratio under the given conditions. Therefore, about 30,000 liters of the product must be applied. Assume the vehicle chosen is a single Piper Pawnee. Then, from Figure 7, it can be seen that an areal density of 40 liters/hectare would result in 9,000 liters being applied per day, or 3.33 days to complete the operation. On the other hand, an areal density of 80 liters/day would result in 11,200 liters/day, or 2.68 days to completion. Thus, doubling the dosage has resulted in about a 20% reduction in the total operating time. This must be

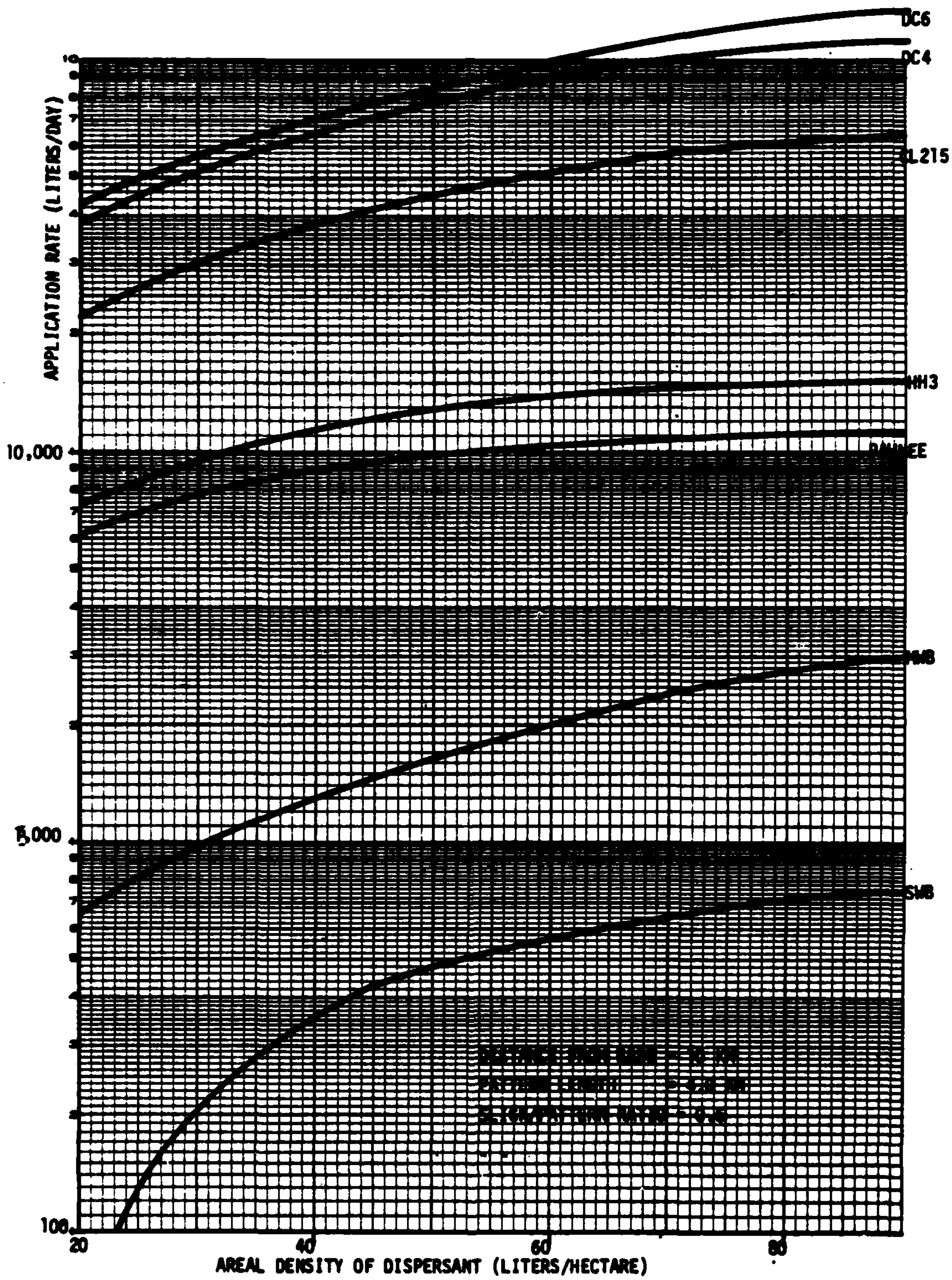


FIGURE 7. APPLICATION RATE VS AREAL DENSITY

weighed against the increased risks of over-dosage presented by the higher dosage rate.

Normalized Cost (Figures 8-11): The cost of application in dollars (1979) per liter as a function of distance from base to slick pattern are shown in Figure 8 for a mean pass length of 0.6 km and in Figure 9 for a mean pass length of 4.0 km. The variation with pass length is shown in Figure 10, and with areal density in Figure 11.

The results seen in Figures 8 and 9 are as follows: for relatively short pattern lengths (L_p = 0.6 km) the DC-6 and DC-4 are the most economic vehicles over 10 km from the operations base, and only slightly less economic than the Pawnee less than 10 km from the base. Operating costs are well under $1.00 per liter for these vehicles. For longer pattern lengths (about 4.0 km, Figure 9) the DC-6 and DC-4 are even more attractive (about $0.20 per liter) than the Pawnee at short distances. Table 7 shows the cost per liter at 0 km distance and the distance at which the cost doubles for each vehicle. The DC-6 and DC-4 have low cost/liter and large ranges, regardless of mean pass length. At the other extreme the B206 and the workboats have high cost/liter and restricted range, regardless of pass length. The Pawnee has low cost but restricted range, regardless of pass length. The CL215 and HH3 are low cost only for the larger pass length, the range of the HH3 being much less than that of the CL215.

The variation of cost/liter with pass length is shown in Figure 10. The workboats and B206 are more expensive than the other vehicles for pattern lengths greater than about 0.3 km (about 1000 feet) but below about 0.5 km the Pawnee is distinctly less expensive than all the other vehicles.

Figure 11 shows cost/liter as a function of the dispersant areal density (liters/hectare). It can be

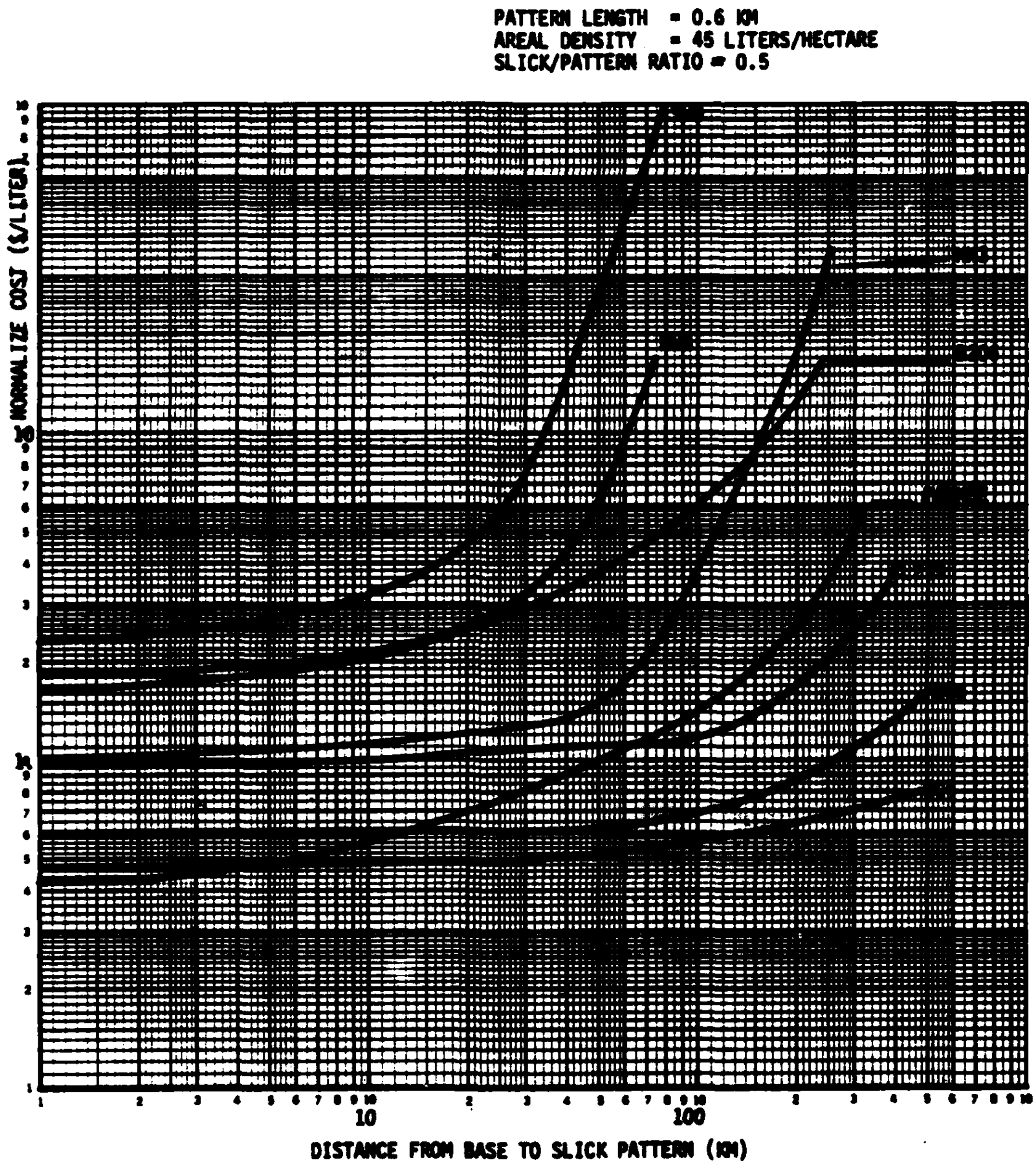


FIGURE 8. NORMALIZED COST VS DISTANCE TO SLICK FOR PATTERN LENGTH = 0.6 KM

PATTERN LENGTH = 4.0 KM
AREAL DENSITY = 45 LITERS/HECTARE
SLICK/PATTERN RATIO = 0.5

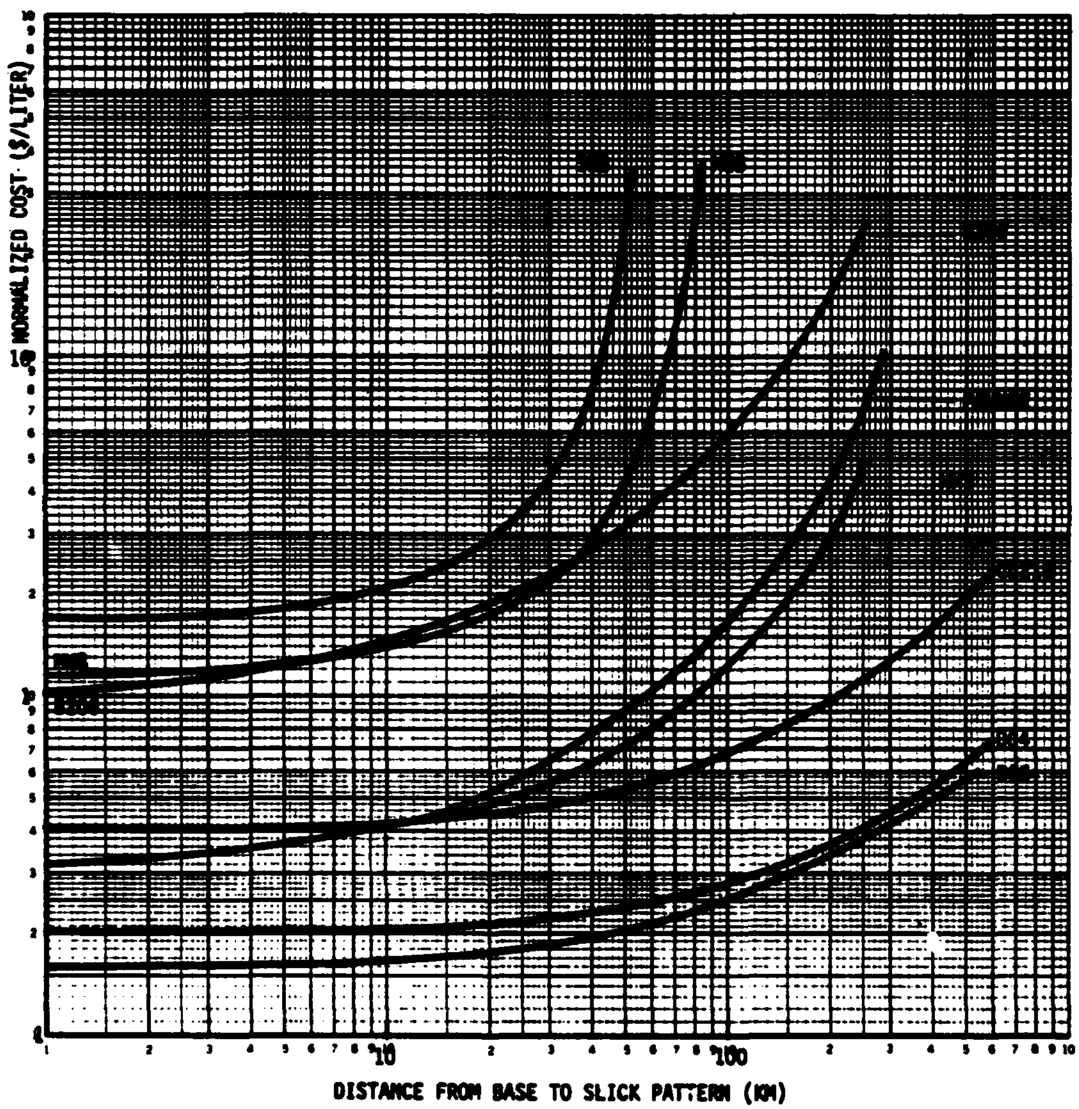


FIGURE 9. NORMALIZED COST VS DISTANCE TO SLICK FOR PATTERN LENGTH = 4.0 KM

TABLE 7. NORMALIZED COST AND DISTANCE FROM BASE AT WHICH IT DOUBLES FOR VARIOUS VEHICLES

Vehicle Type	Cost/liter at D = 0 km	Distance D at which Cost/liter doubles
Pattern Length = L_p = 0.6 km		
DC6	$ .62	340 km
DC4	.47	900
CL215	.98	230
Pawnee	.43	34
HH3	1.01	66
B206	1.66	60
MWB	1.81	34
SWB	2.36	21
Pattern Length = L_p = 4.0 km		
DC6	$ .20	270 km
DC4	.16	180
CL215	.40	140
Pawnee	.32	28
HH3	.33	41
B206	1.00	23
MWB	1.17	36
SWB	1.73	25

N.B. Areal density = 45 liters/hectare
slick/pattern ratio = 0.5

DISTANCE FROM BASE = 10. KM
AREAL DENSITY-=- = 45 LITERS/HECTARE
SLICK/PATTERN RATIO = 0.5

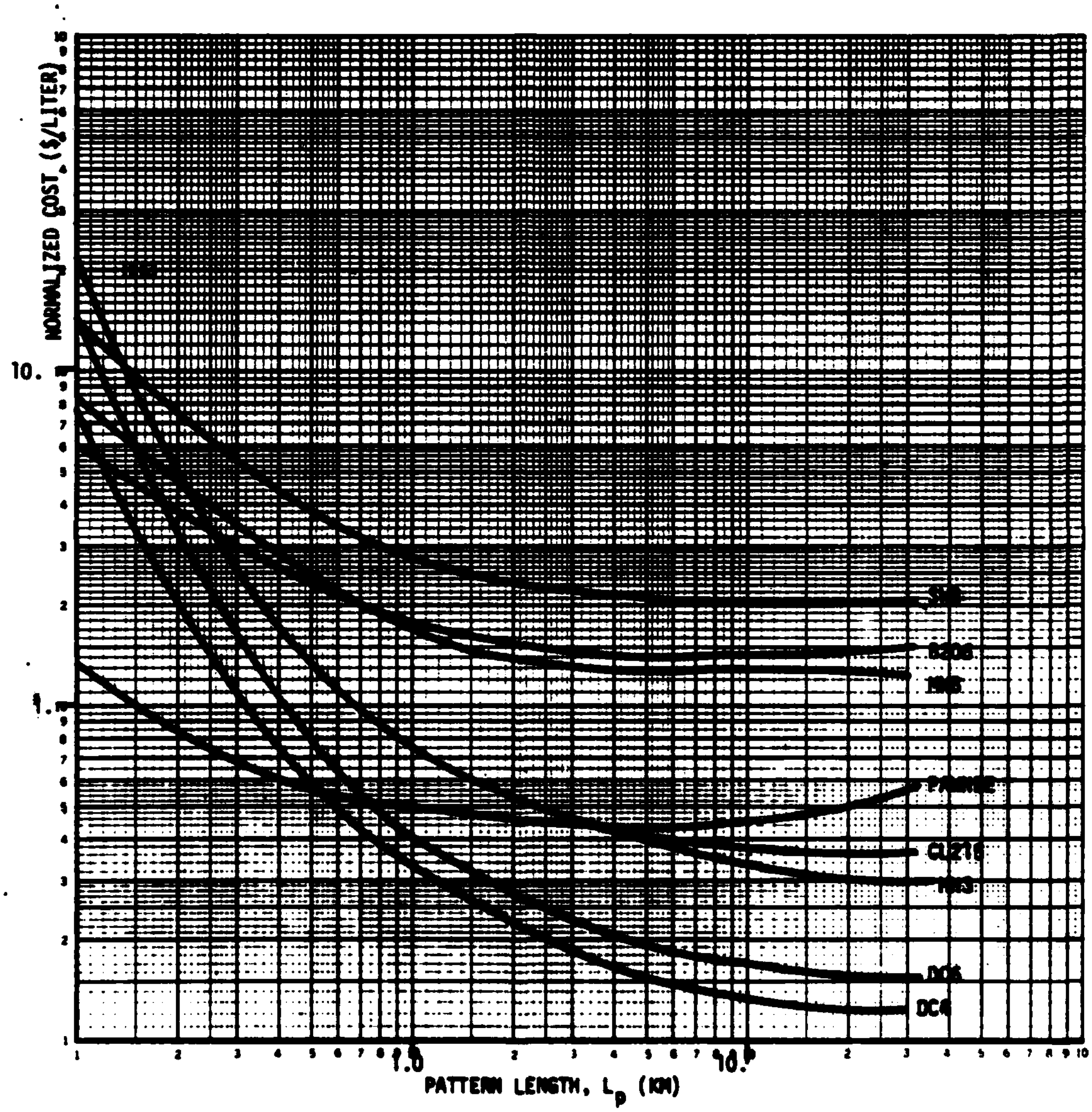


FIGURE 10. NORMALIZED COST VS DISTANCE TO SLICK
FOR PATTERN LENGTH = 10. KM

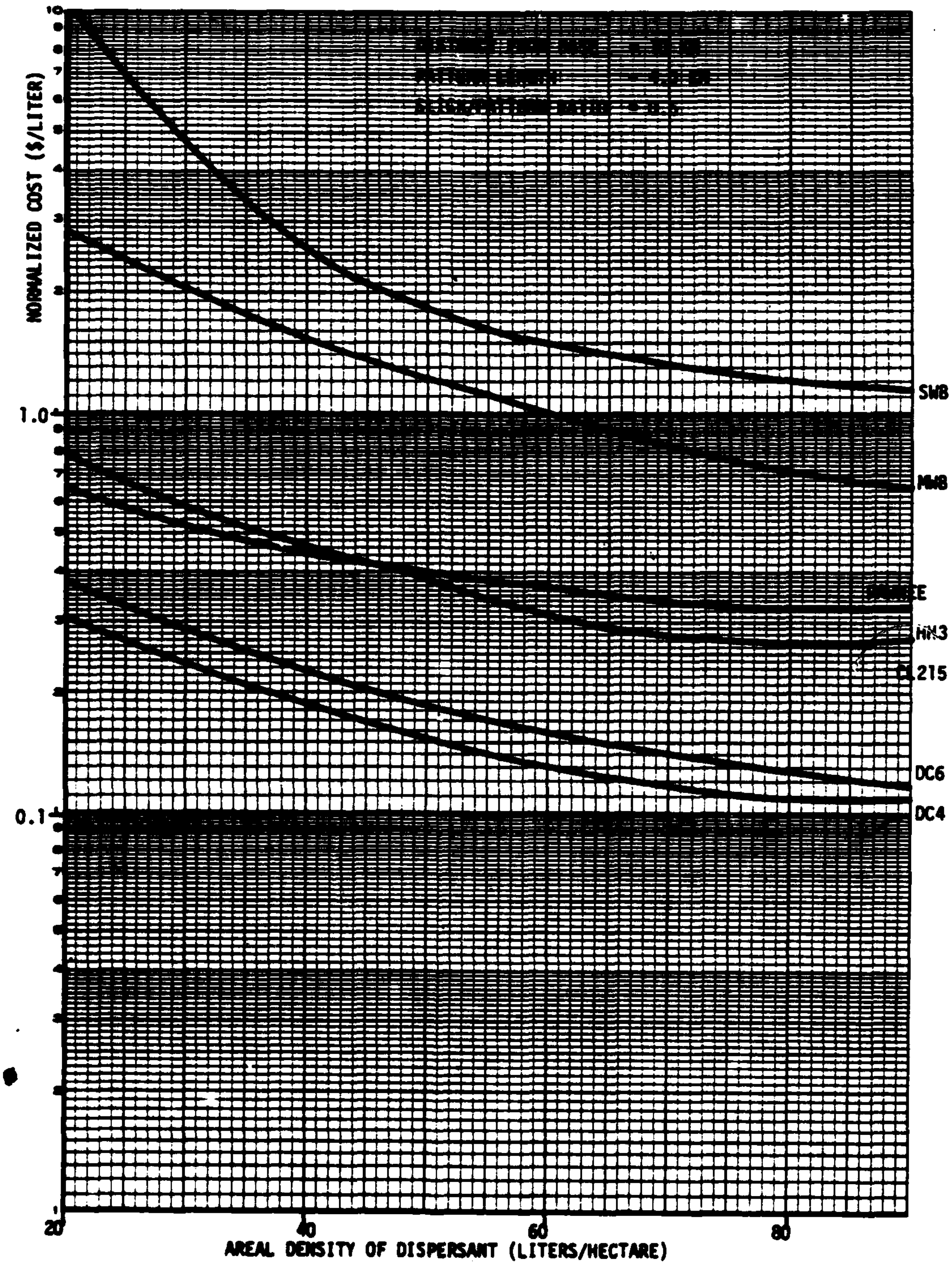


FIGURE 11. NORMALIZED COST VS AREAL DENSITY

seen that doubling the dosage does not cut the cost in half, for the same reason that it does not double the application rate in Figure 7.

Summary of Results

Application Rate: Large Aircraft (DC-6, DC-4, CL215) can apply about 20,000-80,000 liters per day of dispersant with ranges of 200-300 km. Small aircraft (Pawnee, HH3, B206) apply about 3,000-15,000 liters per day at ranges of 30-50 km. Workboats apply 300-2,000 liters per day up to 20-30 km. The DC-6, DC-4, CL215 and HH3 require mean pattern pass lengths of 1.6 km or more for effective application rates, while the Pawnee, B206, and workboats require 0.20 km or more. The DC-6, DC-4 and CL215, however, are still more effective than all other vehicles at pass lengths greater than 0.2 km, and more effective than all but the Pawnee at pass lengths greater than 0.1 km. Finally, doubling the dosage (liters per hectare) results in substantially less than twice the application rate (liters per day).

Cost: The DC-6 and DC-4 have the lowest application cost per liter ($.15-$.65) regardless of pass length, at ranges of 180 km or more. The Pawnee application cost is about $.30-.40 per liter with ranges of 30-40 km. At the other extreme, the B206 and workboats cost from $1.00 per liter to $2.36 per liter with ranges from 20 to 60 km. The application costs for the HH3 and CL215 depend strongly upon the mean pass length. The costs of ferrying, retainer fees, training, spotter aircraft, and of the dispersant itself are not included above.

FACTORS IN DISPERSANT STOCKPILING

The size, location and replenishment of U.S. Coast Guard stockpiles of dispersants depend on a variety of factors, such as

- frequency, size, and location of oil spills
- fraction of spilled oil amenable to chemical dispersion
- frequency of approval of dispersant use under Annex X of the National Contingency Plan
- availability of commercial and cooperative stockpiles of dispersants at the present time
- production capability
- availability of application equipment, vehicles, and trained personnel
- availability of logistic support for transporting dispersant to the operations base
- storage properties of the dispersant

In this section the first two factors and the last five factors will be considered. The third factor, although outside of the scope of this report, deserves brief comment: Some studies (e.g., Reference 3) have concluded that dispersants can be an economically attractive alternative to mechanical methods of spill cleanup as well as to legal damage claims. If this is so, then the industry can be expected to invest heavily in stocks of dispersants when it seems likely that approval for their use under Annex X can be secured at future spills. Hence any indication that approval of dispersant use will be obtained readily (as, for example, a series of actual such approvals) will probably have the effect of stimulating the stockpiling of dispersants by industry, with consequent reduction in the need for Coast Guard stockpiles. This eventuality might have a substantial effect on Coast Guard stockpile planning. For example, of the 3,434,000 liters of dispersant stockpiled in the United Kingdom, 60% is held by companies and the UK Offshore

Operators Association, while 40% is held directly by the UK Department of Transport and Ministry of Defense. (Reference 7)

1. FREQUENCY, SIZE AND LOCATION OF OIL SPILLS

In the period 1974-1977 the United States waters experienced about 20 spills per year of 50,000 USG or more. Approximately the same rate has been sustained in 1978 and 1979. The rate for spills of 1,000 gallons or more is approximately 630 per year, and oil spills of all sizes commonly exceed 10,000 per year in United States waters. Studies have shown that there are no significant differences in spill rates among major coastal areas. (Reference 8)

The largest size spill to have occurred within U.S. territorial waters is 10 million USG (Burmah Agate, Galveston, Texas, 1 November, 1979), but spills in the 50-100 million gallon range are possible off U.S. coasts where lightering of large crude carriers takes place. In general, however, the data on spills are inadequate to provide spill size distributions for separate coastal areas. As a result of these circumstances there is presently available only a single empirical distribution for spill size, and a single spill rate (i.e., spills per million tons of oil movement) for all United States coastal waters. Nevertheless, it is still possible to derive different levels of dispersant stock required in each of several coastal regions. This is possible because the different tonnages of oil movement in different regions result in unequal numbers of spills per year, on the average, in those regions. Areas with more spills (per year, not per ton movement) should be alloted larger stockpiles of dispersant because, having more spills *in toto*, they are more likely to experience one or more large spills.

In order to formulate mathematically the above reasoning it is necessary to make some assumptions. The first is that the U.S. waters have been divided into spill response areas, each served by a single stockpile of dispersants. It is assumed that the only dispersant available for a spill is that in the associated area stockpile, which is replenished after a spill cleanup is completed and before the next spill occurs in that area. Also, it is assumed

that the total amount of dispersant available for all stockpiles is limited. The limit may be chosen on the basis of estimated total national usage, or on the basis of funding availability or environmental considerations, for example.

The next step is to set the objective upon which the allocation is to be based. The one assumed here is that of minimizing the total amount of spilled oil in excess of associated area stockpiles. A spill will go untreated to the extent that it exceeds the capability of the associated stockpile.

With the assumptions above it is possible to formulate and solve the dispersant stockpiling problem in exactly the same way that the general equipment allocation problem was solved for oil pollution response. (Reference 8, Appendix K). The objective function for the ith stockpile is

$$\bar{R}_i = \bar{n}_i \left[r_i - \int_0^{r_i} F_i(x)dx \right],$$

where

$\bar{R}_i$ = average amount of oil dispersed per year by the ith stockpile, tons.

$\bar{n}_i$ = average number of spills treated per year by the ith stockpile.

r_i = dispersing capability of the ith stockpile, in tons of oil.

$F_i(x)$ = distribution of spillsize x in the ith area, x in tons of oil.

The objective function for all N areas is

$$\bar{R} = \sum_{i=1}^{N} R_i,$$

which is to be maximized by choice of the stockpiles r_i, $i = 1, 2, 3, \ldots, N$, subject to the constraints:

$$\sum_{i=1}^{N} r_i \leq K, \text{ and}$$

$$r_i \geq 0, \; i=1, 2, 3, \ldots, N.$$

where K is the total national oil dispersal capability, in tons of oil. Maximizing $\overline{R}$ is equivalent to minimizing the amount of undispersed oil. It will be noted that in this formulation dispersant levels are measured by equivalent tons of oil that they can disperse.

Solutions to the above problem can be found by computer or graphically. (Reference 8, Volume II, Appendix K) To solve the problem it is necessary to have cumulative distribution F(x) of spill size x. It is necessary also to have values $\overline{n}_i$ for the expected number of spills per year in the area covered by each stockpile, i. A graphical solution was worked out as outlined in Reference 8, Volume II, Appendix K using the cumulative distribution of spill sizes for spills over 50,000 gallons (189,250 liters) in the U.S. in 1974-77, taken from Reference 8, Vol. I, p. 21. This cumulative distribution is shown in Figure 12. The values of $\overline{n}_i$ employed were derived from the same spill data as were employed to produce this figure, with adjustment for the 1980-1990 time frame. The values of $\overline{n}_i$ are shown in Table 8. The eleven stockpile locations in Table 8 are the bases that serve eleven spill response regions covering the U.S. coastal waters within 12 hours in 97% of historic spill cases.

The dispersant stockpiles that result from the calculation are given in Table 9.A and the percent of oil treated is given in Table 9.B.

The realism of the above formulation is limited primarily by the assumption that a spill is treated only from the stockpile in

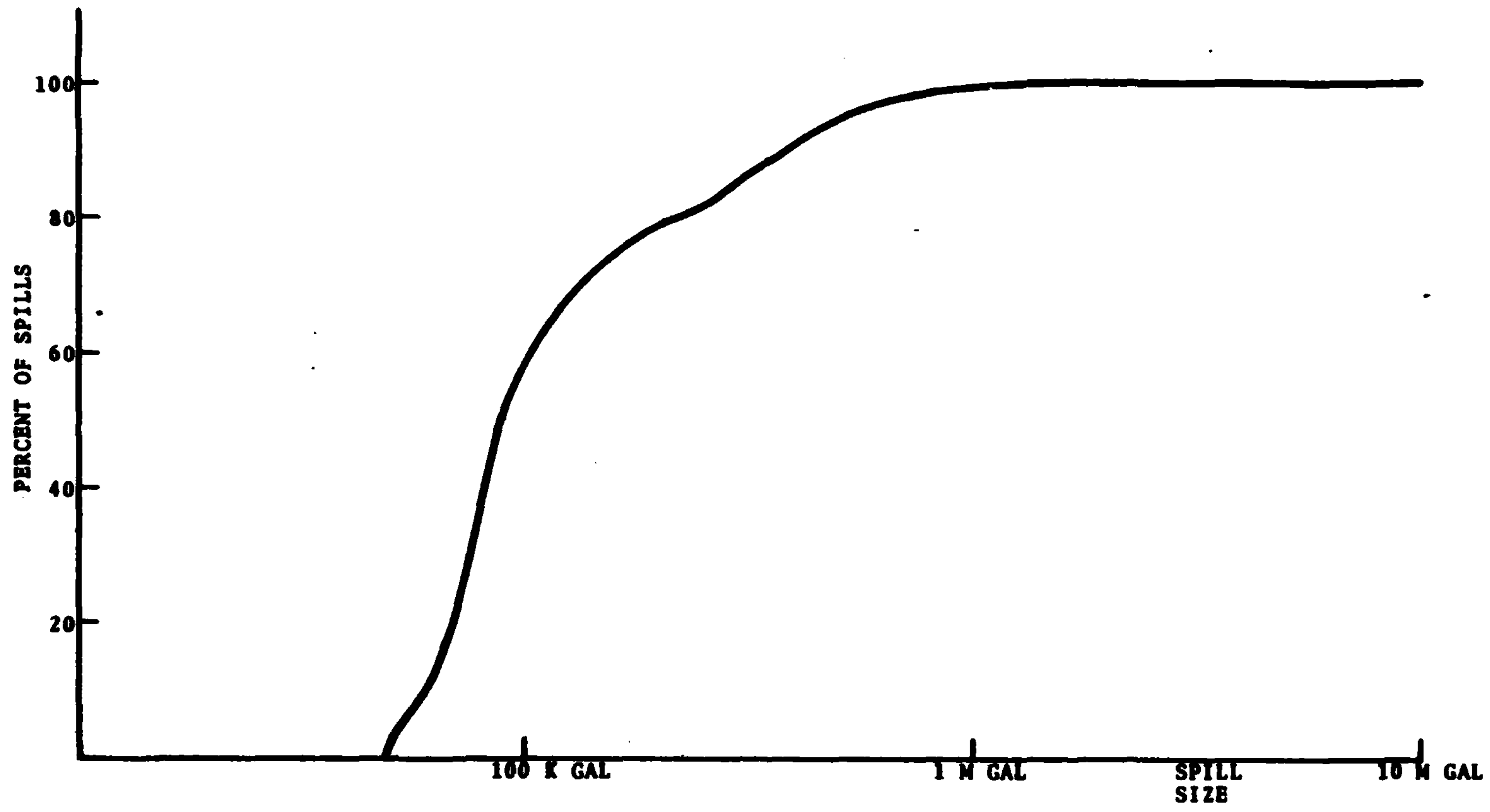


FIGURE 12. CUMULATIVE DISTRIBUTION OF SPILL SIZE
(SPILLS OVER 50,000 GAL IN US, 1974-1977)

TABLE 8. ANNUAL SPILLS IN U.S. COASTAL REGIONS SERVED BY ELEVEN SPILL RESPONSE BASES

	i, Stockpile Location	n_i, Expected Number of Spills/yr
1.	Elizabeth City, NC	0.84
2.	Bay St. Louis, MS	3.97
3.	San Francisco, CA	1.84
4.	New York, NY	2.19
5.	Philadelphia, PA	2.37
6.	Boston, MA	1.43
7.	Miami, FL	0.63
8.	Galveston, TX	3.08
9.	Los Angeles, CA	1.61
10.	Seattle, WA	0.52
11.	Kodiak, AK	3.60
		22.08

Notes: (1) Spills served by closest stockpile
(2) Based on national spill rate for spills of 50,000 US gallons or more

TABLE 9A. PERCENT OF TOTAL DISPERSANT CAPABILITY DISTRIBUTED OVER ELEVEN STOCKPILES

	NATIONAL DISPERSAL CAPABILITY (MILLIONS OF TONS OF OIL)				
	5.4 MT	3.8 MT	2.9 MT	2.4 MT	1.9 MT
Elizabeth City, NC	6.5%	4.7%	3.9%	3.8%	4.3%
Bay St. Louis, MS	12.0	13.9	15.0	16.3	17.7
San Francisco, CA	9.3	10.1	9.5	8.3	7.8
New York NY	10.0	10.7	11.2	10.4	9.4
Philadelphia, PA	10.4	11.2	11.6	11.5	10.9
Boston, MA	8.5	8.5	7.1	6.0	6.0
Miami, FL	5.3	3.4	3.1	3.3	3.6
Galveston, TX	11.5	12.5	13.6	13.8	14.6
Los Angeles, CA	8.7	8.9	8.3	6.9	6.8
Seattle, WA	4.4	3.1	2.8	2.9	2.7
Kodiak, AK	12.6	13.3	13.9	15.0	16.1

TABLE 9.B AVERAGE PERCENT OF SPILLED OIL THAT CAN BE TREATED WITH DISPERSANTS FROM ELEVEN STOCKPILES

	5.4MT	3.8MT	2.9MT	2.4 MT	1.9 MT
Elizabeth City, NC.	92%	62%	60%	53%	52%
Bay St. Louis, MS	100	97	96	94	90
San Francisco, CA	98	92	85	76	68
New York, NY	99	94	89	82	73
Philadelphia, PA	99	95	91	84	77
Boston, MA	98	88	77	67	59
Miami, FL	85	61	51	50	46
Galveston, TX	100	96	95	90	85
Los Angeles, CA	98	89	81	71	63
Seattle, WA	81	61	44	46	34
Kodiak, AK	100	97	95	92	88
US Weighted Average	98%	92%	87%	78%	76%

its area, which stockpile is not replenished until after the spill response is complete. This is unrealistic because

(1) Dispersant can be transported, with some delay, from other stockpiles;

(2) Manufacturers can usually provide an almost continuous flow of their product, given time for production start-up.

As a result, a more realistic picture of dispersant availability in time would look somewhat like that of Figure 13. It should be noted that "other stockpiles" includes those of the manufacturer, companies and cooperatives, as well as Coast Guard and U.S. government stockpiles. The actual step sizes in this plot would be affected by logistics as well as by the stockpile sizes.

Another improvement in realism can be achieved by taking account of the (possibly) limited capability to apply dispersant. The capability may be limited by availability of suitable vehicles, or by weather. In that case, the amount of dispersant actually applied as a function of time would resemble the dashed line of Figure 14.

Modifying the allocation model to take account of other stockpiles, problem (1) above, is possible (Reference 8, Vol. II, Appendix K). The modification, however, is accomplished by assuming that a quantity q of dispersant from a remote stockpile is equivalent to a fraction, of αq, of its normal capacity. The fraction α is chosen to be smaller for more remote stockpiles, and larger for the closer stockpiles; $\alpha=1$ for the stockpile of the region in which the spill occurs. Although this "coefficient of effectiveness" model is somewhat artificial it does provide improved answers to the problem. The arrival of dispersant from manufacturer's stockpiles, problem (2) above, might also be approached by this model. But extending the model to account for limited delivery capability presents formidable difficulties. Considering these difficulties, and the artificiality of the "effectiveness coefficient" approach, it seems to be of limited practical value to extend the allocation model to allow for limited delivery capability.

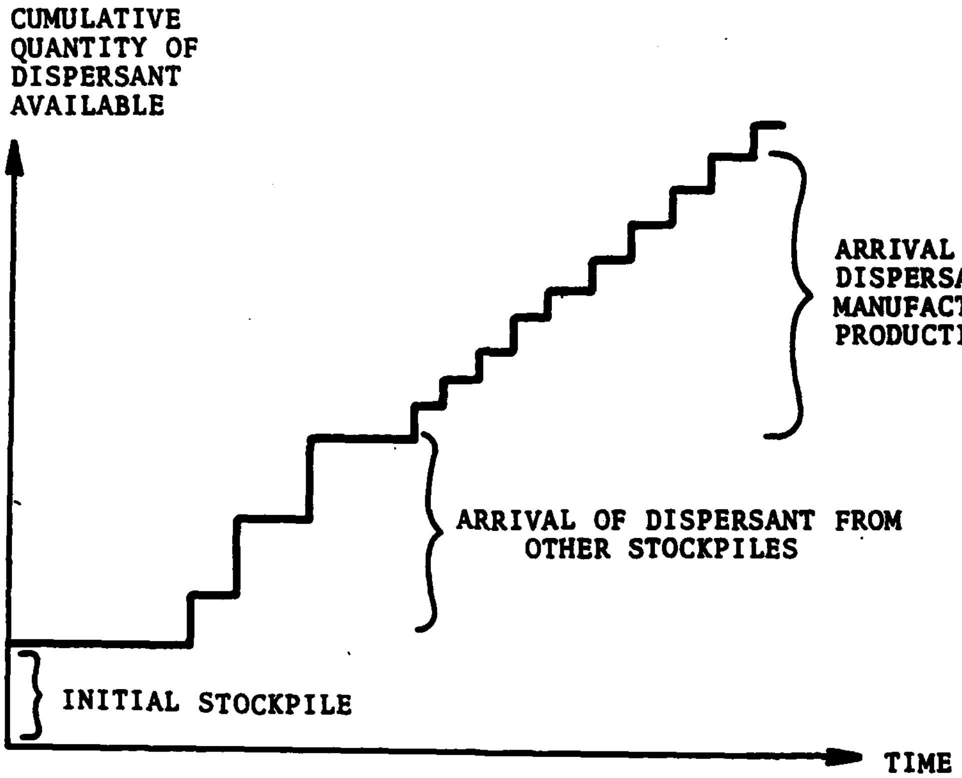


FIGURE 13. HYPOTHETICAL PLOT OF DISPERSANT AVAILABILITY AS A FUNCTION OF TIME

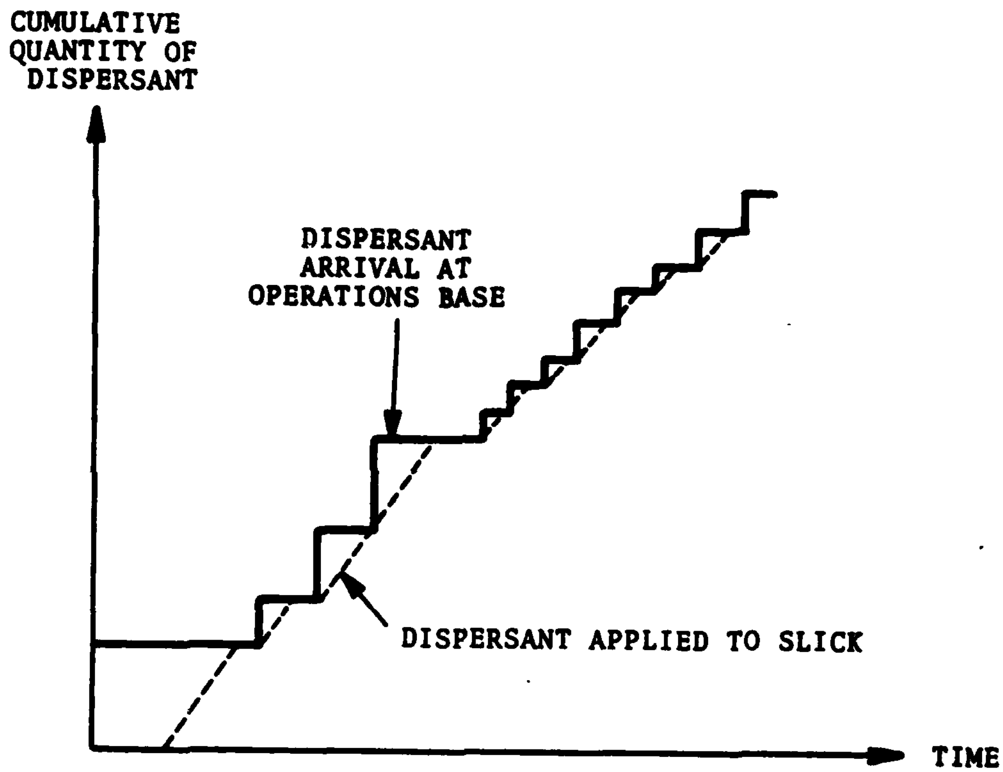


FIGURE 14. DISPERSANT AVAILABILITY AND APPLICATION AS FUNCTIONS OF TIME

2. FRACTION OF SPILLED OIL AMENABLE TO DISPERSANTS

The amount of dispersant required to treat a spill depends not only on the ratio of dispersant to oil (effectiveness ratio) but also on what fraction of the spilled oil needs to be treated. Unlike mechanical cleanup methods, dispersants can have undesirable ecological effects so that they are employed only if the following processes are inadequate:

1. mechanical cleanup
2. evaporation and dissolution
3. transport to sea by wind and currents.

Further, dispersants are likely to be used only when some ecologically sensitive shoreline, or natural amenity, is threatened by the oil.

<u>Open Water</u>

Historically, mechanical cleanup of spills in open water has recovered only a small fraction of the spilled oil. Mechanical cleanup also cannot be expected to be effective in rivers, channels and other areas of high currents. All tolled, mechanical cleanup cannot be expected to reduce spill size by more than 5%-10% on the average, as a rough estimate.

Evaporation commonly removes a substantial fraction of spilled oil. It can be expected to remove 80%-90% of gasoline, kerosene and light distillate spills in 12 hours or less, depending on water temperature and oil composition. It can remove from 20% to 40% of crudes within one day; but the evaporation loss from residual oils is usually less than 10%. If oil shipments by water are 40% crude, 30% light distillates, and 30% residual oils, then average evaporative losses might be estimated as $\bar{E}$,

$$\bar{E} = .4 \times 30\% + .3 \times 80\% + .3 \times 10\%$$
$$= 40\%$$

The transport of oil slicks to sea is not a substantial effect for spills in rivers and harbors. Tidal currents, which reverse every six hours, are likely to bring a harbor spill ashore in a day, or less, all other influences being absent. If a spill occurs near open shoreline, natural spreading alone will tend to bring about half of it on shore. The farther the spill site is off shore, however, the less the likelihood of it reaching shore in a specified time. If the center moves at a constant speed v, and in a constant but randomly selected direction from the spill location, then the probability of it reaching the shoreline in time t is $(\cos^{-1}d/vt)/\pi$. (Figure 15) The upper limit of the probability is 0.5 in this crude model. In reality the probability of impact will be closer to 1.0 if the winds are onto the shore, and closer to 0.0 if they are coming off the shore. For example, the Argo Merchant slick moved 160 km in 6 days, an average speed of 1.1 k/h, corresponding to a mean wind speed of from 24.7 to 31.7 km/h (15.4 to 19.8 mph) almost due east. Had the direction been westerly the slick would have impacted Nantucket in 48 hours.

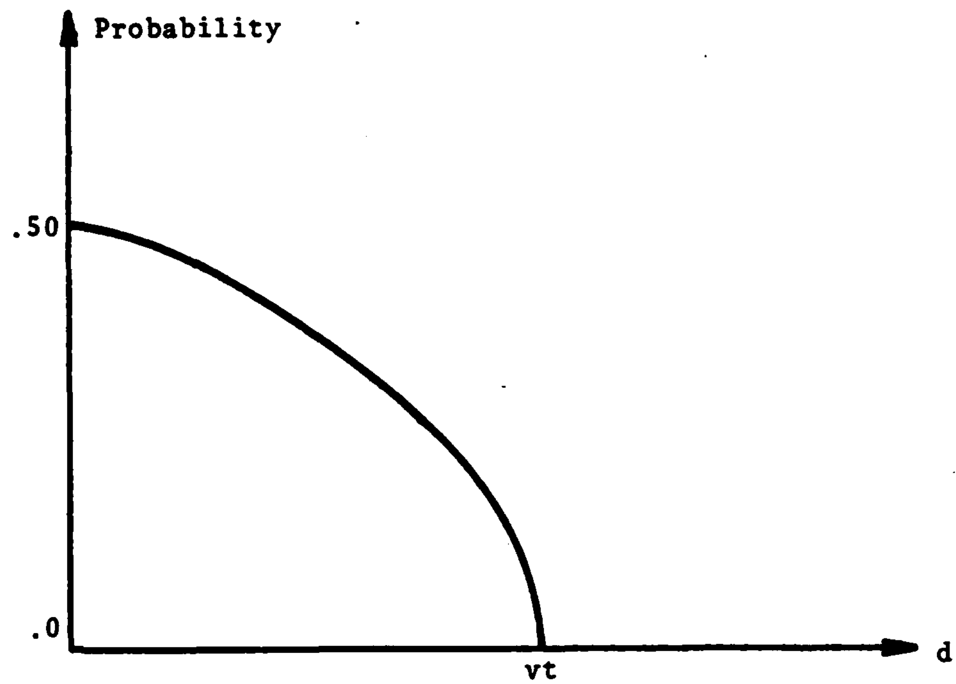
The final consideration mentioned above in the use of dispersants is that of the type of shoreline threatened by the oil. The fraction of U.S. coastline that would be excluded from dispersant treatment, if dispersants were generally employed, is almost impossible to estimate at present. Eventually, local contingency plans covering all coastal areas will detail the ecological sensitivity of each shoreline section. These data, conceivably, could be used to pre-determine the use of dispersants in each such section. At present, however, it is difficult to exclude any section of shoreline from potential dispersant use, as opposed to any other section.

In summary, the crude estimates made above on the fraction of spilled oil amenable to dispersant treatment in open waters result in:

5% recovered by mechanical means,

40% of the unrecovered portion evaporated or dissolved,

50% of the remainder carried out to sea,



v = slick speed
t = time from spill
d = distance from shore

FIGURE 15. PROBABILITY OF A SLICK IMPACTING A SHORELINE IN TIME t.

leaving about 29% to be treated with dispersants. It should be noted that the fraction of oil carried out to sea is more accurately the fraction of spills not requiring treatment and as such should be used instead to reduce the mean spill rates $\bar{n}_i$, rather than to scale down the results of the algorithm. This would give a somewhat different set of distributions of dispersant among the stockpiles than is shown in Table 9A. Considering the inaccuracies in the estimate, however, practically equivalent results are obtained by using the landfall probability to reduce spill size, as above.

The assumption that about 29% of each spill is amenable to dispersal allows one to reduce the total national capability, and all stockpiles, by that factor. The percentage distributions shown in Tables 9A and 9B remain unchanged but the total national dispersal capability at the head of each column would be multiplied by .29.

The above calculation is based on spills greater than 50,000 USG between 1974-1977. A more accurate result would be obtained if all spills greater than, say, 1 USG for the period 1974-79 were employed. Also, the above calculation does not allow for differences in dispersability with location, i.e., northern waters are assumed to have no effect on the dispersability of spills; the same .29 factor is applied to spills at all locations.

Confined Waters

The above calculation must be modified for spills in confined waters such as harbors and bays and canals. In such cases mechanical cleanup is much more effective, as was the case in the Gowanus Canal or at West Hackberry, LA. A rough estimate of mechanical recovery effectiveness in such cases is 50%. This applies to recovery of oil from the water, rather than to beach or shoreline cleanup. Evaporation effects are about the same as for open water, i.e., about 40% can be assumed to evaporate. Transport to sea is usually very small, say 5%-10%.

In summary, the rough estimate above lead to an overall fraction of about 27%-29% of the oil spilled in confined waters that could be subject to application of dispersants.

3. NON-USCG STOCKPILES AND PRODUCTION

An inventory of U.S. stockpiles of dispersants is given in Volume I. The results are summarized in Table 10. These supplies are of dispersants having data accepted by the U.S. Environmental Protection Agency, held by companies and cooperatives in the U.S., and available for U.S. Coast Guard use as of February 1980. (Some cooperatives and companies hold supplies committed to specific users, outside of U.S. waters, which supplies are not included in Table 10.) The total stockpiles available for U.S. use are seen in the table to be about 0.44 million liters of all types. The stockpiles in the United Kingdom are about eight times these levels, being about 1.65 million liters of ordinary and about 1.79 million liters of concentrate dispersant.

In addition to stockpiles, one must consider production capability. A short period of time (in the order of a few days) is usually required to start up production, after which a daily production can be sustained for long periods. Table 11 shows production lead times and rates for dispersant production in the same regions given in Table 10. Lead times are given approximately in parentheses, in days. Delivery times must be added to these lead times, to be discussed next.

4. DISPERSANT TRANSPORTATION

Several options for transporting dispersants from stockpiles to the operations base are available, depending on distance, quantity and packaging. Under the Massive Spill Logistics Contingency Plan prepared for the Coast Guard, it would be the responsibility of the Logistics Coordinator to expedite the movement of non-USCG supplies to a spill, if the supplier is unable to provide timely transportation. The stockpiles listed in Table 10 are in 55-USG drums except for about 13% of the hydrocarbon stockpile, which is in 25-liter pails, and part of the concentrate which is in 90- and 180-BBL tanks.

TABLE 10. AVERAGE DISPERSANT INVENTORIES AVAILABLE TO THE U.S. COAST GUARD IN FEBRUARY 1980 - LITERS

Region	Water-Based	Hydrocarbon	Concentrate
New England (ME to CT)	3,100.	-	62,500.
Mid-Atlantic (NY to NC)	26,000.	27,900.	-
South East (SC to AL)	20,800.	5,400.	-
Western Gulf (MS to TX)	90,600.	12,900.	54,900.
West Coast (CA to WA)	47,700.	5,400.	1,700.
Alaska (AK)	-	-	75,400.
Total U.S., liters	188,200.	51,600.	194,500.
Total U.S., gallons	49,700.	13,600.	51,400.
Total U.S., tons	167.	45.	170.
Total U.S., BBL	1,183.	324.	1,224.

TABLE 11. AVERAGE DISPERSANT PRODUCTION AVAILABLE TO THE U.S. COAST GUARD IN FEBRUARY 1980 - LITERS/DAY

Region	Water-Based	Hydrocarbon	Concentrate
Mid-Atlantic (NY to NC)	65,600.(1)	11,000.(1)	-
South East (SC to AL)	99,000.(7)	-	-
Western Gulf (MS to TX)	78,000.(1) 93,700.(7)	52,000.(7)	52,000.(1) 125,000.(7)
West Coast (CA to WA)	52,000.(1)	-	-
Total U.S., liters per day	195,600.(1) 192,700.(7)	11,000.(1) 52,000.(7)	52,000.(1) 125,000.(7)
Total U.S., gallons per day	51,700.(1) 50,900.(7)	2,900.(1) 13,700.(7)	13,700.(1) 33,000.(7)
Total U.S., tons per day	172.(1) 167.(7)	10.(1) 48.(7)	10.(1) 110.(7)

NOTES: (a) Numbers in parentheses indicate approximate start-up time, days.

(b) No production in Alaska or New England.

55-USG DRUMS

The options available are:

1. Conventional platform semi-trailers and tractors. These can carry approximately 50,000 lb load (for an 80,000 lb CGW unit) which is approximately 100 drums at 55 USG per drum. A simpler loading scheme would be 1 layer of upright drums on a 40' x 8' flatbed, resulting in about 80 drums (4400 USG, 16,654 liters) per load. The loaded semi-trailer weighs approximately 52,000 lb.

2. Low-bed semitrailers, such as are used for some USCG pollution control equipment. These have a bed of 8' x 23', which would carry about 46 drums (2530 USG, 9,576 liters) per load. The loaded semitrailer weighs approximately 30,550 lbs.

3. Either loaded semitrailer may be transported by C141, provided by the Department of the Air Force under memo of understanding with the Coast Guard. The C141 can accommodate one loaded conventional flatbed (52,000 lb) plus one loaded low-bed (30,550 lb) over a range of 2500 statute miles. Alternately it can transport two loaded low-beds over 4000 statute miles.

4. The Coast Guard C130H can accommodate one loaded low-bed semitrailer over about 3000 n. mi.

5. Either the C141 or C130H or C130B can be loaded with the drums on conventional 9' aircraft pallets, each pallet containing sixteen 55-gallon drums, and weighing about 8300 lbs. The resultant load/range relations are:

C141	10 pallets	160 drums	2500 s. mi.
	5 pallets	80 drums	5000 s. mi.
C130H	4 pallets	64 drums	1000 n. mi.
C130B	3 pallets	48 drums	500 n. mi.

This method takes longer to load than 3. or 4. above but results in about a 50% increase in dispersant payload for the C141 and about a 33% increase for the C130H.

6. Commercial air freight can be obtained for about $.04/per 100 lb/n. mi. but unless high fees are paid to reserve cargo aircraft for immediate use, delivery times of 1-5 days can be expected. Although these lead times are not suitable for the initial phases of a spill response they are often within the time frame of an extended spill cleanup, such as might occur from an offshore well blowout.

10-, 15- and 25-liter Pails

A small part of the inventory listed in Table 10 is contained in 25-liter pails. These packages are inefficient to move and should be discounted for other than local use.

Storage Tanks

Inventories held in portable tanks up to 8' diameter are amenable to transportation by flat-bed trailer. Tanks of about 100 BBL (4200 USG) can be transported by conventional flat-bed semitrailer of 50,000 lbs capacity. Larger tanks cannot be easily transported except by transferral to a motor tank truck or rail tank truck. Motor tank trucks are readily available to hold and transport up to 9,000 USG, at purchase prices up to $100,000. Rail tank cars are commonly available in 80,000 USG sizes but other sizes are also available. Storage tanks of the 90 BBL variety require a crane for loading and offloading on a semitrailer or vessel. Motor tank-trucks must be loaded and unloaded by pump; petroleum motor carriers commonly are outfitted with pumps for offloading.

The availability of the above transport modes may be characterized in terms of hours required from the time the decision is made to use the mode to the time of arrival at the operations base. These times are estimated for 55-USG drums

in terms of D, the distance from stockpile to operations base, for D $\geq$ 25 n. mi., in Table 12. Here D is in nautical miles, on a great circle from stockpile to operations base. Unloading time at the operations base is not included. It can be seen that the most rapid delivery results from pre-loaded semi-trailers at short distances from the operations base. At distances D of 112 n. mi., it is quicker to be taken to an airport for loading onto a USCG C130 aircraft. If only a DOD C141 is available, instead of the C130, then the breakeven distance is 277 n. mi. instead of 112 n. mi. The availability times for various modes are shown in Figure 16 as a function of straight line distance D from stockpile to operations base.

For large tank storage the air mode is feasible since an 8' diameter storage tank containing 80 BBL of dispersant weighs about 30,000 lbs (about the same as a loaded low bed semi-trailer) and fits into both the C130 and C141. A C130H can accommodate one such storage tank, and a C141 can accommodate two. Ranges are the same as for the loaded low-bed semitrailer.

5. AVAILABILITY OF APPLICATION VEHICLES

Large Fixed-Wing

Because of their very high application rates, few of these aircraft are required for even large slicks. Moreover, their large ferry range makes it possible to draw from suppliers in the west and north-west of the U.S., where several firms operate DC4's and DC6's for forest fire and agricultural purposes. Hence, availability is not usually a problem for large fixed-wing aircraft, but delivery times can range from 1 to 3 days depending on time of year and other demands.

Small Fixed-Wing

The application rates achievable with these aircraft are such as to require 20 to 50 to treat medium to large slicks (Reference 2). Such numbers of agricultural spraying aircraft are

TABLE 12. DISPERSANT DELIVERY TIMES BY VARIOUS MODES FROM STOCKPILE TO OPERATIONS BASE-55 USG DRUMS

1. USCG tractor semi-trailer carrying 55 USG drums:
   (a) drums preloaded: .25 + D/33.33 hours
   (b) drums in storehouse: 2.0 + D/33.33 hours

2. Rental tractor and semi-trailer, hauling 55 USG drums from USCG or other stockpile:
   (a) minimum: 4.0 + D/33.33
   (b) average: 6.0 + D/33.33

3. USCG tractor semi-trailer carrying 55 USG drums to local airport; C130 flight of semi-trailer and load to destination airport; tractor semi-trailer over the road to operations base:
   (a) preloaded: 3.25 + D/300.
   (b) not preloaded: 5.00 + D/300.

4. Same as 3. except C141 aircraft is employed instead of USCG C130:
   (a) preloaded: 8.0 + D/500.
   (b) not preloaded: 8.0 + D/500.

5. 55 USG drums on pallets loaded onto aircraft at USCG air base by forklift, operating from stockpile at airport; loaded onto semi-trailer or truck at destination airport, then hauled to operations base:
   (a) using USCG C130: 2.0 + D/300.
   (b) using DOD C141: 8.0 + D/500.

6. Same as 5. except destination airport is also the operations base:
   (a) using USCG C130: 1.0 + D/300.
   (b) using DOD C141: 7.0 + D/500.

TABLE 12. DISPERSANT DELIVERY TIMES BY VARIOUS MODES FROM STOCKPILE TO OPERATIONS BASE-55 USG DRUMS (CONTINUED)

Assumptions for Table 12.

1.	Tractor/semi-trailer inspection time	.25 hours
2.	Time to load semi-trailer onto aircraft	.50 hours
3.	Time to load drums onto semi-trailer	2.00 hours
4.	Time to remove semi-trailer from aircraft	.50 hours
5.	Delivery time for rental tractor/semi-trailer	
	minimum	2.00 hours
	average	4.00 hours
6.	Distance from stockpile to airport	33.33 n. mi.
7.	Distance from airport to operations base	
	vessel application	33.33 n. mi.
	aircraft application	0.00 n. mi.
8.	Time for delivery of C141 to USCG base	6.00 hours
9.	Time to load pallets on aircraft	.50 hours
10.	Time to unload pallets from aircraft	.50 hours

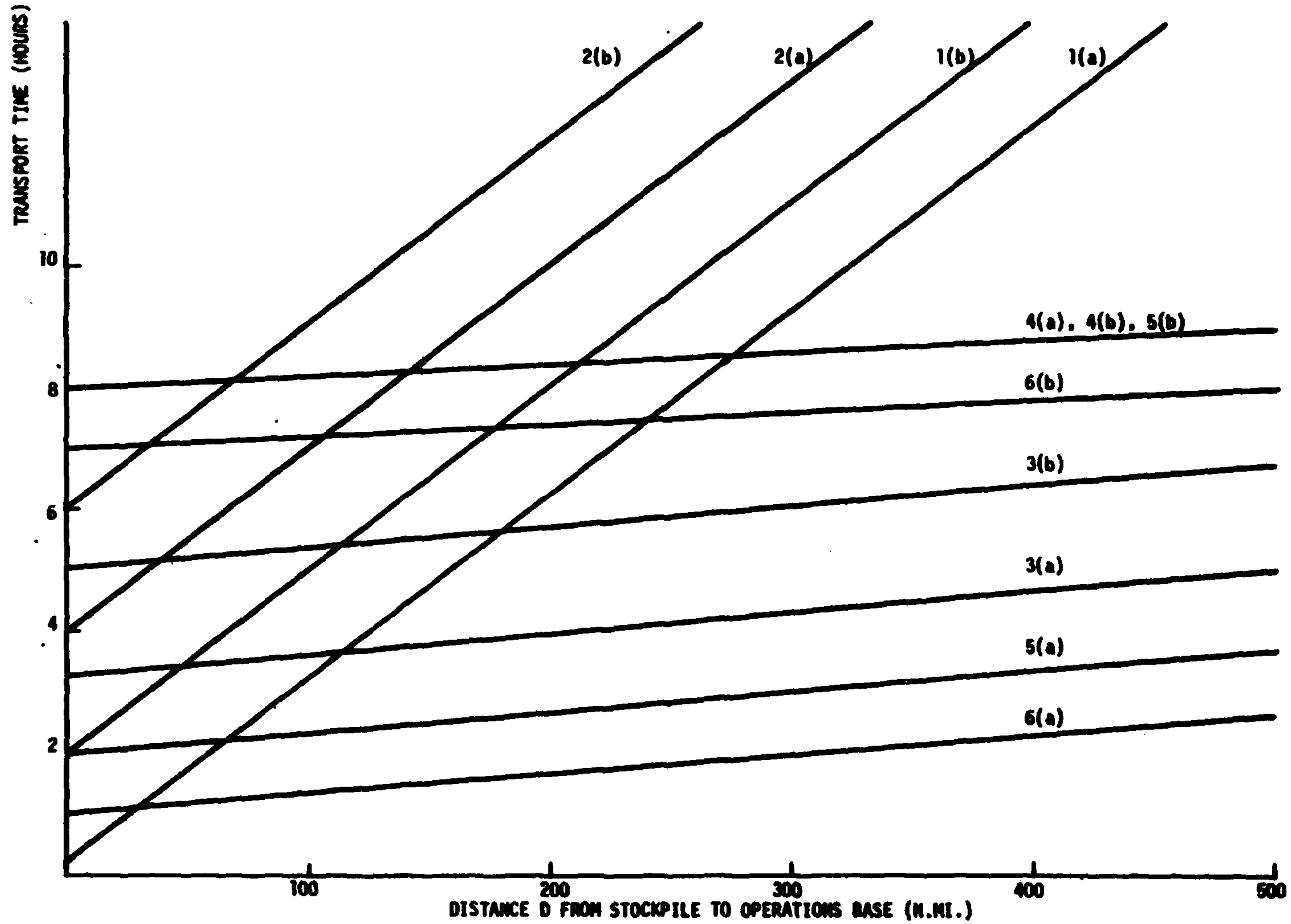


FIGURE 16. DISPERSANT DELIVERY TIMES BY VARIOUS MODES FROM STOCKPILE TO OPERATIONS BASE - 55 USG DRUMS (FROM TABLE 21.)

not only difficult to locate in some coastal areas, but are impractical to coordinate safely. It is more likely that small agricultural aircraft will find use in small or medium spills.

Helicopters

Commercial helicopters are less plentiful than small fixed-wing aircraft, and more expensive, but more versatile because of their minimal landing area requirements and lower speed. USCG helicopters are stationed near all major ports, are almost always available and can lift considerably more payload than the Bell 206A and 206B commonly available commercially. These are approximately 29 USCG HH3 vehicles stationed in the 50 states.

WorkBoats

The availability of applicator vessels in most port areas is excellent, if it is not required that they be pre-fitted with spray booms. Harbor and river tugs can often substitute for workboats. The availability of spray booms is the limiting factor, therefore, for vessel application. At present, there are less than six spray boom rigs ready for service in the United States. Unlike spray aircraft, spray vessel equipment is specialized to oil dispersal and hence is sensitive to the prospects for increased or diminished use of dispersants.

6. STORAGE PROPERTIES OF DISPERSANTS

Storage properties include not only shelf life, but the associated storage conditions, such as temperature, and the need for agitation or special containers. Products that can be stored in a variety of conditions, for long periods of time, with little or no maintenance cost are preferred. They place less restriction on the stockpiling strategy, which can be formulated on the basis of the six factors just discussed.

The storage properties of thirteen dispersants for which data have been accepted by the EPA are discussed in Volume I and also in the following section of this Volume. Annex X of the National Contingency Plan requires the manufacturer to submit technical data

regarding the "maximum and minimum storage temperatures to include optimum ranges as well as temperatures that will cause phase separation, chemical changes or otherwise damage effectiveness of the chemical agent." Generally, the data submitted do not state the basis on which the minimum or maximum storage temperatures are determined, and they must be modified in some cases by phase separation and/or freezing point temperatures which are not always given under Annex X. Further, shelf life in some cases is stated as "unlimited". Finally, if the actual storage temperatures are below the minimum pumpability temperature of the dispersant for part of the year, the storage area may have to be heated partly in order to maintain the product fluid enough to be used on short notice.

The implications of the above uncertainties is that any stockpiles may be expensive to maintain because of the need for heating and/or maintenance (such as periodic agitation). Also, if, even under "optimum" conditions the dispersant has a short shelf life, their stockpiles will have to be replaced periodically at additional cost. Therefore it may be concluded that improvement of storage characteristic data is important to the stockpiling question.

A fuller discussion of the storage and handling problems presented by dispersants is given in the following section.

FACTORS IN DISPERSANT SELECTION

Volume I of this study report details the logistics-related properties of thirteen oil spill dispersants for which data have been accepted by the EPA under Annex X of the National Contingency Plan. The findings contained in that report are summarized here for the reader's convenience.

1. HANDLING PROPERTIES

The handling and storage properties of the 13 subject dispersants are summarized in Table 13, under the three categories: water-based, hydrocarbon-based, concentrate. The major considerations are:

(1) Fire or Explosion Hazard: Of the several indicators of fire or explosion hazard, the most useful is flash point, which is given in the Annex X data submissions. The eight water-based products all have flash points above 212°, rendering them virtually free of fire hazard, with one exception. The hydrocarbon and concentrate products had flash points above or close to 105°F, but less than 200°F, requiring caution in handling and storage. Only one dispersant has a flash point low enough (116°F) to cause serious concern. It is necessary to fully assess the fire/explosion hazard of this and any other products with flash point below 150°F.

Except for the one product with an excessively low flash point, none of the dispersants present a serious fire or explosion hazard and selection need not be restricted.

(2) Toxicity and Causticity: The best guide available to these properties is the labelling requirements of the Federal Hazardous Substances Act. Most of the hydrocarbon and concentrate products, and one of the water-based products, are labelled irritant. Hence it would seem that the use of gloves, goggles and clothing to cover the skin are important for those products. However, prolonged exposure would make precautions advisable even for the other products.

TABLE 13. SUMMARY OF STORAGE AND HANDLING PROPERTIES OF THREE DISPERSANT TYPES

	W								H			C	
Product #	1	2	3	4	5	6	7	8	10	11	13	9	12
Pour Point													
H: >20°F			✓		✓	✓	✓	✓					
M: 0°- 20°F	✓	✓		✓									
L: < 0°F									✓	✓	✓	✓	✓
Flash Point													
H: >212°F	✓	✓	✓		✓	✓	✓	✓					
M: 150°-212°F									✓	✓	✓	✓	
L: <150°F				✓									✓
Viscosity @100°F													
H: >100 SSU	✓	✓		✓	✓	✓	✓	✓				✓	
L: <100 SSU			✓						✓	✓	✓		✓
Min Storage Temp													
H: >20°F					✓		✓					✓	✓
M: 0°-20°F	✓			✓		✓				✓			
L: < 0°F		✓	✓						✓		✓	*	
Shelf Life													
H: >60 mos		✓		✓		✓		✓	✓	✓	✓	✓	✓
M: 36-60 mos					✓		✓						
L: <36 mos	✓		✓										
Combustible				✓					✓	?	✓	✓	?
Irritant				✓					✓	?		✓	?

Notes: W = waterbased, H = hydrocarbon-based, C = concentrate
H,M,L = high, medium, low

*Manufacturer's data sheet.

Provided the Coast Guard personnel are properly trained and equipped to handle them, none of the dispersants present a serious toxicity or causticity hazard.

(3) Pumpability: Pumpability is indicated approximately by pour point, but cannot be determined adequately without viscosity data. Annex X data on pour point shows that all the hydrocarbon and concentrate products have pour points of 0°F or below, making them good candidates for use in Alaska. It is doubtful that any of the water-based products can serve in Alaska, and some of those with pour points above 20°F may be unsuitable for use in New England, the Great Lakes or the Northwest. The Annex X data on viscosity is inadequate to resolve those questions, because they give viscosity at 100°F. This is well out of the range of interest for determining pumpability properties (0°F to 35°F). Hence, it is inadvisable to select any of the thirteen dispersants for use in the northern U.S. without further data on viscosity.

(4) Reactivity: The chemical action of the subject dispersants on equipment does not appear to offer any serious problems or limitations on their storage, application methods, or use.

2. STORAGE PROPERTIES

(1) Temperature: The question of minimum required storage temperature is of more concern than that of maximum storage temperature. Although Annex X requires data on minimum allowable storage temperature, the basis on which such temperatures are determined is not usually stated and consequently they must be modified by phase separation and/or freezing points where available. The relation of minimum storage temperature and minimum use temperature is such that either one can limit the climatic conditions in which the dispersant may be employed. If pour point is used as surrogate for minimum usable temperature, then there are very large differences, both positive and negative, between minimum storage and minimum use temperatures. Moreover, there is no consistency within the groups of water-based, hydrocarbon-based or concentrate dispersants with regard to minimum storage temperatures.

The implications of the above for dispersant selection are that the Annex X data are not adequate to determine the conditions under which a heated storage area is required for any given product.

As pointed out in the preceding section, there are substantial implications for the question of stockpiling.

(2) Shelf Life: The thirteen subject dispersants show shelf lives from 18 months to "unlimited".

The EPA-accepted dispersants have shelf lives stated as follows (in ascending order)

1 product	:	18 months
1 product	:	greater than 24 months
1 product	:	24 to 60 months
1 product	:	greater than 36 months
3 products	:	greater than 60 months
3 products	:	indefinite
3 products	:	unlimited

The economic value of a long shelf life depends on restock policy, production lead time and production level. Although Warren Spring Laboratory specified 5 years minimum shelf life, the value of that specification needs to be assessed for U.S. stockpiles and production capabilities.

The shelf-life requirement suitable for a USCG-stocked dispersant must be determined in the overall context of a dispersant deployment strategy.

3. APPLICATION CHARACTERISTICS

The major characteristics bearing on dispersant application are described below by ten parameters. Information for the subject dispersants relative to four of the parameters (Water Salinity, Equipment Type, Agitation, Mixing) is summarized in Table 14.

TABLE 14. SUMMARY OF APPLICATION CHARACTERISTICS[1] OF THREE DISPERSANT TYPES

	W								H			C	
Product #	1	2	3	4	5	6	7	8	10	11	13	9	12
Salinity													
Fresh	✓	?	✓	?	✓	✓	✓	✓	?	✓	✓	x	
Brackish	✓	?	✓	?	✓	✓	✓	✓	?	✓	✓	✓	
Salt	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Equipment Type													
Hand Tanks		✓	✓	✓	✓				✓	✓	✓	✓	
Dispersant Pump		✓		✓	✓		✓			✓	✓	✓	
Eductors		✓	✓	✓		✓	✓	✓			✓	✓	
Dual Pump			✓	✓							✓	✓	✓
Aerial		✓	✓	✓		✓						✓	
Extra Agitation													
Essential					✓		✓	✓		✓	✓		✓
Desirable	✓	✓	✓	✓		✓			✓			✓	
Mixing Ratios													
Neat	✓	✓	✓	✓	✓		✓		✓	✓	✓	✓	✓
≤1:20	✓		✓	✓			✓					✓	✓
>1:20		✓	✓	✓		✓	✓	✓					

Notes: (1) Based on manufacturer's recommendations

W = water-based, H = hydrocarbon-based, C = concentrate
✓ = recommended, x = not recommended, ? = not clear

(1) Oil Type, Weathering and Emulsification: There is evidence that dispersants vary in effectiveness on different types of oil. Some results are available from the Canadian Environmental Protection Service, covering 4 of the subject dispersants and four types of oil. (Reference 10.) The US EPA effectiveness tests cover the 13 subject dispersants for No. 2 and No. 6 oils. These results show a great deal of variability among dispersants and from oil to oil. Although the EPA data show water based dispersants to be significantly less effective than the hydrocarbon or concentrate dispersants after 2 hours on No. 2 oil they show no significant difference on No. 6 oil. (Volume I, Appendix A)

(2) Slick Thickness: Thicker oil slicks impede the penetration of dispersant and retard dispersion. Differences among dispersants in slick penetration, however, are largely unknown.

(3) Water Temperature: Two of the 13 subject dispersants showed about a 23% drop in effectiveness in 40°F water compared to 62°F water, based on Canadian Coast Guard tests on a crude oil, Reference 11. Similar results have been reported by the Canadian EPS, Reference 10. The results seem to suggest that the drop in effectiveness is similar for most dispersants, but full comparative data do not yet exist.

(4) Water Salinity: About 30% of US oil movement is in fresh water (e.g., the upper Delaware River). (See Volume I, Table 9.) Eight of the 13 products are recommended by their manufacturers for use on fresh water spills; four bear no explicit recommendation, and one product is recommended only for salt or brackish water spills. See Table 14. Actual effectiveness comparisons for salt and fresh water, however, are available for only four of the 13 dispersants.

(5) Wave Conditions: Many dispersant manufacturers imply in their literature that wave action alone can produce effective dispersion in some cases. An interpretation of their literature can be taken (Table 14) showing that six of the 13 producers consider agitation

other than wave action to be essential to dispersion with their product, while all state that external agitation will improve the dispersion.

(6) Shoreline Type: It is generally recommended by the EPA that dispersants not be used for beach protection (i.e., application before the fact). Further experience has shown that effective dispersant application on an oiled beach can drive the oil into the sand, thus delaying its microbial degradation. This reduces the likely uses of dispersants on shorelines to the cases of rocks, cobbles and other impenetrable surfaces. It is not proven that hydrocarbon-based dispersants are superior to water-based dispersants for such use.

(7) Equipment Types: Five different application methods were considered in Volume I, each having restrictions with regard to dispersant dilution, mixing, and agitation. Dispersant manufacturer recommendations on application method and mixing and agitation lead one to typify the methods/dispersant matches as follows:

1. Hand Carried Pumps: These are useful on shorelines and in boats near piers, rocks, etc. Because capacity is limited, dispersants selected should be effective when applied neat or only slightly diluted. All product manufacturers, except four, recommend their product for such application, as shown in Table 15, but even those four products may be suitable for hand carried use.

2. Dispersant-Pump Systems: When used on shore, these devices are similar in requirements to 1. When used on a vessel, dispersants requiring higher dilution ratios, say up to 1:20, are possible in addition to neat application. The suitable dispersants are products #2, #4, #5, #7, #9, #11, #13 as shown in Table 15, although the other products also may be found to be suitable.

3. Pump-Eductor Systems: These are high-pressure/high-volume water pump systems. Several water-based products (#2, #3,

TABLE 15. APPLICATION METHODS RECOMMENDED BY DISPERSANT MANUFACTURERS

Disp. Product #/Type	Hand-carried Spray Tanks -land	Hand-carried Spray Tanks -boat	Disp. Pump Syst.	Pump-Eductor Syst.	Dual Pump Syst.	Aerial Spray Syst.	Note
1/W	- no specific application methods recommended -						
2/W	X	X	X	X		X	(1)
3/W	X			X	X	X	
4/W	X	X	X	X	X	X	
5/W	X	X	X				
6/W				X		X	(2)
7/W			X	X			
8/W				X			
9/C		X	X	X	X	X	(3)
10/H	X	X				X	
11/H	X	X	X				
12/C					X		(3)
13/H	X	X	X	X	X		

(1) In calm waters additional agitation may be needed for aerial application.

(2) Dilution with 20 parts fresh or salt water recommended for aerial application.

(3) Has been applied by air in tests or actual spill or both.

#6, #7, #8) were apparently designed primarily for this type of equipment (see Tables 15 and 16). The hydrocarbon-based products, except #13, are not intended for this type of application. One of the concentrates is recommended for eductor use (specifically, by fire hose).

4. Dual Pump Systems: These systems allow better control of the dispersant: water ratio. The method is recommended for the two concentrates but is also advantageous for dispersants that are effective at low dilutions, such as product #1, #3, #4, #7 and #13.

5. Aerial Application: Aerial application is suitable only for dispersants that are effective (a) when applied neat, and (b) without the addition of agitation. Six manufacturers describe their products as suitable for aerial application, but the effectiveness of these products without agitation is generally not documented. (See Table 15).

(8) Agitation: Most dispersants are increased in effectiveness if agitation is applied, provided adequate contact time is allowed. The so-called "self-mixing" dispersants (products #9 and #12) have been found to be "effective in promoting the dispersion of Kuwait crude" at a 1:20 application ratio (Reference 5).

(9) Mixing, Dilution: Products designed for pump-eductor systems (see above) are more effective when mixed with large amounts of water at time of application. Pre-dilution of dispersants, if done before storing, effectively creates a new dispersant product.

(10) Application Ratio: This is a critical parameter in dispersant operations. Manufacturer recommendations range from 1:1 to 1:80 or more, but the available sea trial data seems to indicate 1:20 to 1:8 for Corexit 9527 and BP1100WD, used on Kuwait or Tia Juana crude. (References 5 and 11.)

TABLE 16. MANUFACTURER'S MIXING[1] RECOMMENDATIONS

Product/Type	Neat	Mixed, Type of Water	Mixing Ratios
1/W	Yes	Yes, Fresh or Salt	1:5 - 1:40
2/W	Yes	Yes, Fresh or Seawater	1:40 - 1:80
3/W	Yes	Yes, Fresh or Salt	1:10 - 1:40
4/W	Yes	Yes, Fresh or Seawater	1:5 +
5/W	Yes	No	
6/W	No	Yes, Fresh or Salt	1:20 - 1:500
7/W	Yes	Yes, Fresh or Salt	1:15 - 1:50
8/W	No	Yes, Fresh or Seawater	1:20 - 1:80
9/C	Yes	Yes, Seawater	1:10 - 1:20
10/H	Yes	No	
11/H	Yes	No	
12/C	Yes	Yes, Seawater	1:9
13/H	Yes	Yes, Fresh or Seawater	

[1] Mixing here means dilution at time of application

4. EFFECTIVENESS

The application characteristics described determine effectiveness, i.e., the dispersant : oil ratio required to achieve a given percent dispersion, or percent dispersion achieved by a given dispersant : oil ratio. The greater the effectiveness, the fewer the problems of stockpiling, transporting, and applying the dispersant. The present EPA tests for effectiveness are of limited use in establishing effectiveness rankings among the subject dispersants because they are limited to No. 2 and No. 6 fuel oils, which give significantly different rankings. They do not cover any crude oils, which are of major interest, nor do they allow for effectiveness variation with agitation level, temperature, or salinity.

5. AVAILABILITY

The total US inventory of the subject dispersants was about 2050 drums, as of February 1980. Total productive capacity is about 2500 drums/day. At a 1:20 application ratio, the above inventories could treat about 7,500 tons of oil plus 9,000 tons per day. The largest single product inventory in the US can treat at least 3,400 tons of oil, plus at least 1,400 tons per day, at a 1:20 application ratio. (Volume I, Tables 17 and 18.)

6. COST

Prices of the subject dispersant ranged from $4 to $11 per gallon in February 1980. Water-based dispersants averaged $7.57/gallon and hydrocarbon-based dispersants averaged $6.34/gallon. Concentrates averaged $9.45/gallon. At a 1:20 application ratio, the materials cost of treating a ton of oil is about $115 using the average-priced dispersant. But significant differences in cost can occur because of variations in effectiveness.

7. CONCLUSIONS

The conclusions are drawn from EPA Technical Product Bulletins, published reports, and manufacturer's literature for the thirteen dispersants for which the EPA has accepted data as of October 1979.

1. Although full hazard assessment data should be obtained for all products, it appears that all the dispersants but one have adequately high flash points for normal use.
2. Toxicity, causticity and reactivity information indicates that no handling problems can be expected from those sources, assuming normal precautions are observed. These precautions include, for some products, use of gloves, goggles and protective clothing.
3. Data are generally inadequate to determine minimum practical storage temperature. The most significant deficiencies occur in regard to viscosity, freezing points, and phase separation points.
4. Shelf life requirements need to be established in the context of inventory data, inventory strategy, and production capability.
5. There are no published data on effectiveness for most of the dispersants applied to crude oil. Canadian and UK sea tests on Kuwait and Tia Juana crude showed full dispersion at 1:20 to 1:8 ratios for two of the dispersants, with and without agitation.
6. EPA-accepted data for effectiveness on No. 2 oil show no significant correlation with data on No. 6 oil. They also show water-based dispersants to be significantly less effective than hydrocarbon-based on concentrates on No. 2 oil, but not on No. 6 oil. They do not cover variation of effectiveness with water temperature, slick thickness or agitation level.

7. Dispersants can differ substantially in effectiveness on fresh vs salt water. A significant part of US oil movement (over 30%) takes place in fresh or brackish water.

8. Pre-dilution requirements have little impact on logistics. Requirements for mixing with water at the time of application have a strong impact on application method.

   - Three dispersants are recommended only for neat application (no mixing). They are suitable for hand carried tanks, dispersant pump systems and, possibly, aerial application.

   - Four dispersants are recommended primarily for high mixing ratios (>20 parts water to 1 part dispersant). They are best suited to eduction systems.

   - Six dispersants are recommended for a range of mixing ratios from 1:0 (neat) to about 1:20 (or more). They are suitable for all types of application methods.

9. Although a dispersant may be suitable for application by a particular method, it may have low effectiveness when so applied. This is particularly true for aerial application which precludes externally applied agitation.

10. Application ratio required for effective dispersion is a critical parameter but seems to have been established in part for only two of the dispersants.

11. Present inventories of all manufacturers in the US can treat about 7,500 tons of oil plus 9,000 tons/day: The largest single product inventory can treat at least 3,400 tons of oil, plus at least 1,400 tons/day. These estimates assume a 1:20 dispersant : oil application ratio, a highly variable quantity.

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OPERATIONAL STRATEGIES FOR DISPERSANT USE

The preceding sections of this report have analyzed the major operational factors in the use of oil spill dispersants by the U.S. Coast Guard. They are:

1. Choice of application technique
2. Stockpile locations and sizes
3. Choice of dispersants

These three factors are essential to any operational strategy for dispersant use. The purpose now is to formulate several possible operational strategies and to evaluate them in regard to total cost and response effectiveness. The first steps will be to summarize the conclusions that can be drawn from the preceding sections on the three key factors.

1. CHOICE OF APPLICATION VEHICLES

The DC6, DC4 and CL215 are far superior to the other vehicles in dispersant application rate for pass lengths above 0.2 km and for all distances from operations base to slick pattern. For pass lengths under 0.2 km, the Pawnee has a higher application rate up to about 12 km from base to spill. Practical considerations, however, make it impossible to employ fixed-wing aircraft close to piers or bridges, in narrow harbors, or along shorelines with prominent bluffs, irregular shape or large structures. In those conditions the HH3 or B206 are the obvious choices, from the point of view of application rate.

From the point of view of cost, the conclusion is similar: The DC6 and DC4 have the lowest cost per liter except for pass lengths less than 0.6 km and distances less than 10 km, where the Pawnee is superior, and except for operations close to obstructions such as bluffs or buildings or bridges where the helicopters are superior.

The above conclusions are shown pictorially in Figures 17 and 18. In these Figures it is assumed that:

(a) the operations base is on the shoreline, or within 1-2 kilometers of the shoreline.

(b) the shoreline is obstructed for a distance of about 1.0 km to sea.

If assumption (a) does not hold then the maximum distance from shore at which the Pawnee is preferred (10 km) must be reduced by the amount that the Pawnee operations base is inland from the shore.

If assumption (b) does not hold, then the maximum distance from shore at which the HH3 or B206 are preferred (1 km) should be reduced.

Figures 17 and 18 are very similar, and hence have been combined into a simpler chart (Figure 19) showing the vehicle of choice in different operating regimes. The striking feature of these charts, of course, is that the workboats appear nowhere.

The normalized costs employed do not incluae retainer fees or ferrying costs. Retainer fees will be incurred if the spray operation is delayed because of weather conditions, lack of dispersants, etc., or if it is required to have immediate response. Ferrying costs are normally incurred if the vehicle must be brought from a distance to the operations base. Typical retainer fees (References 3 and 5) are:

DC-6B	$3800/day	345,000/yr
DC-4	2600	120,000
Pawnee	850	
Bell 206	1250	
MWB	2400	
SWB	1200	

Ferrying costs are not more than application costs and a reasonable conservative estimate is to set them equal to application cost.

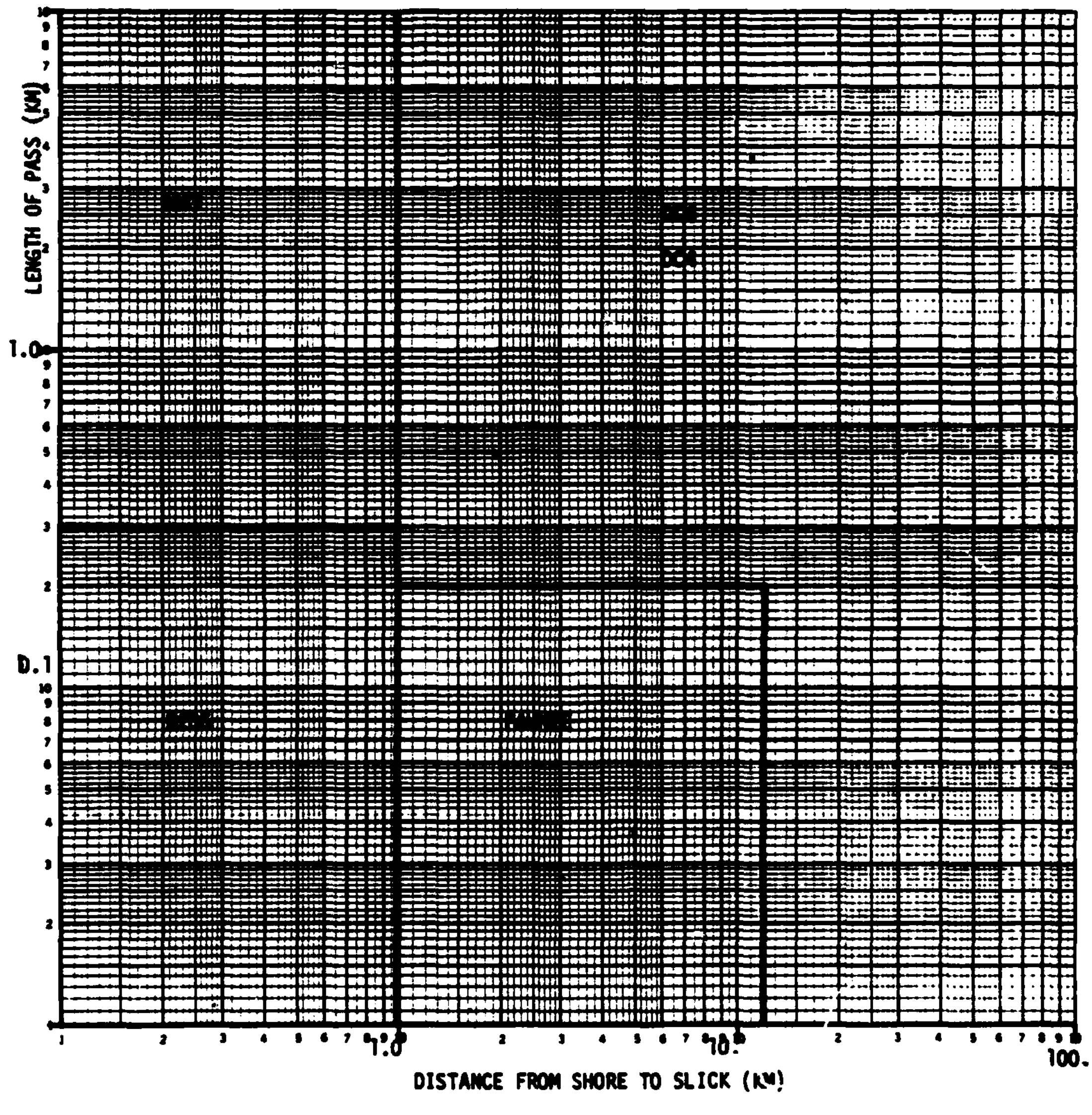

FIGURE 17.. VEHICLES HAVING GREATEST APPLICATION RATES IN VARIOUS REGIMES

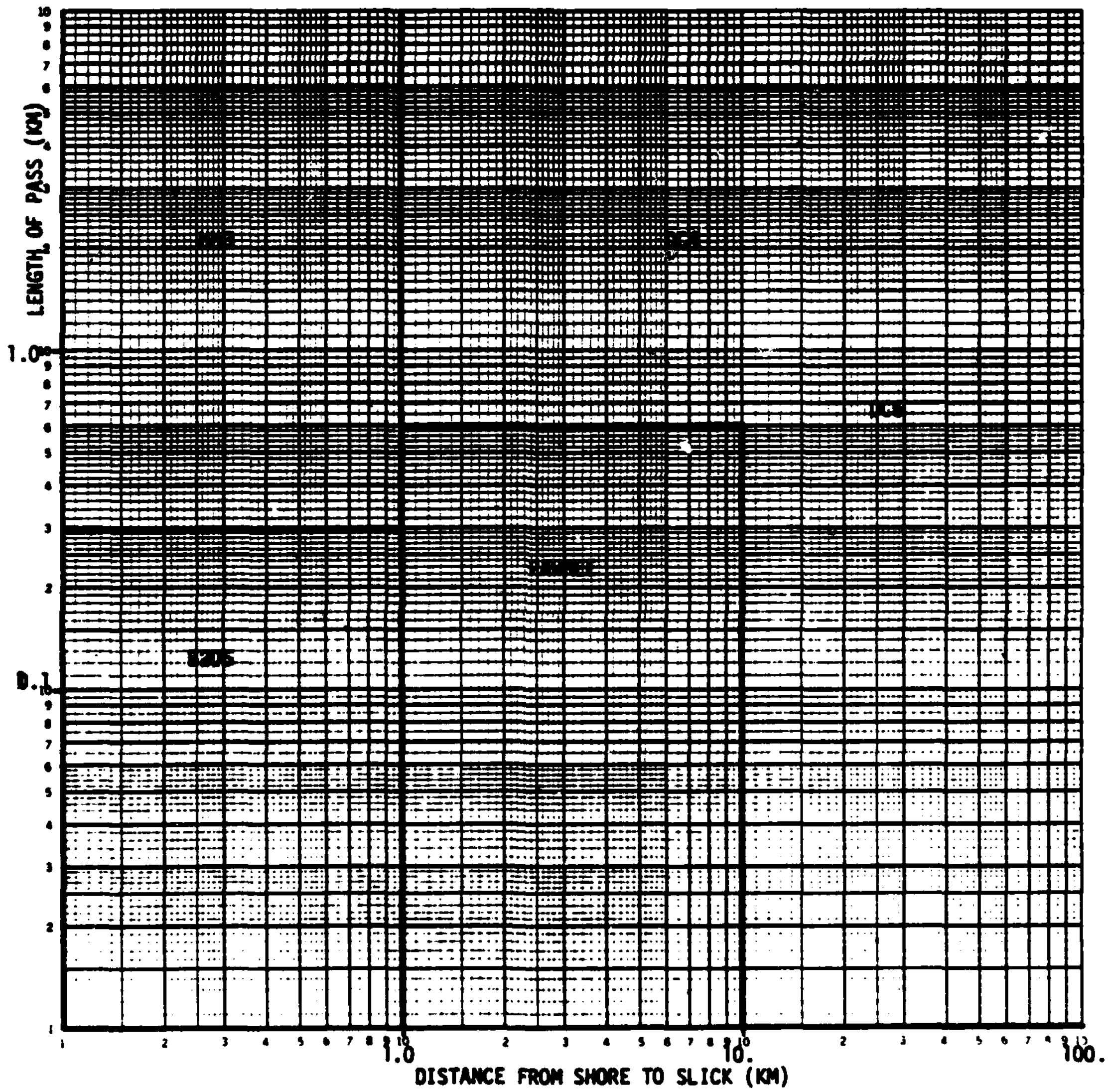

FIGURE 18. VEHICLES HAVING LOWEST NORMALIZED COSTS IN VARIOUS REGIMES

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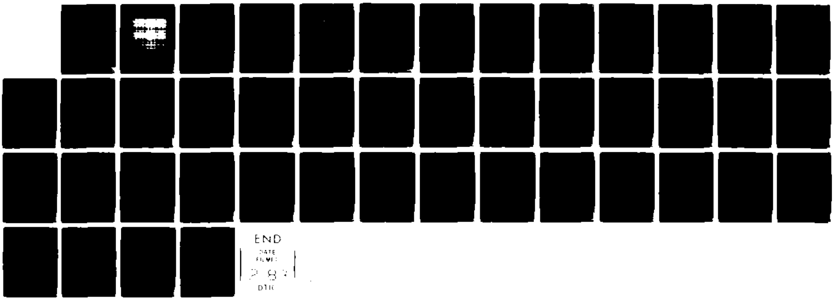

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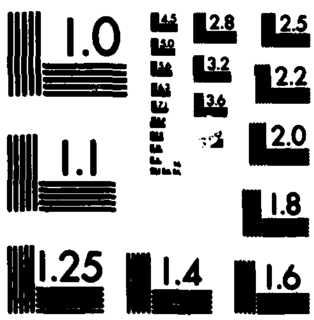

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

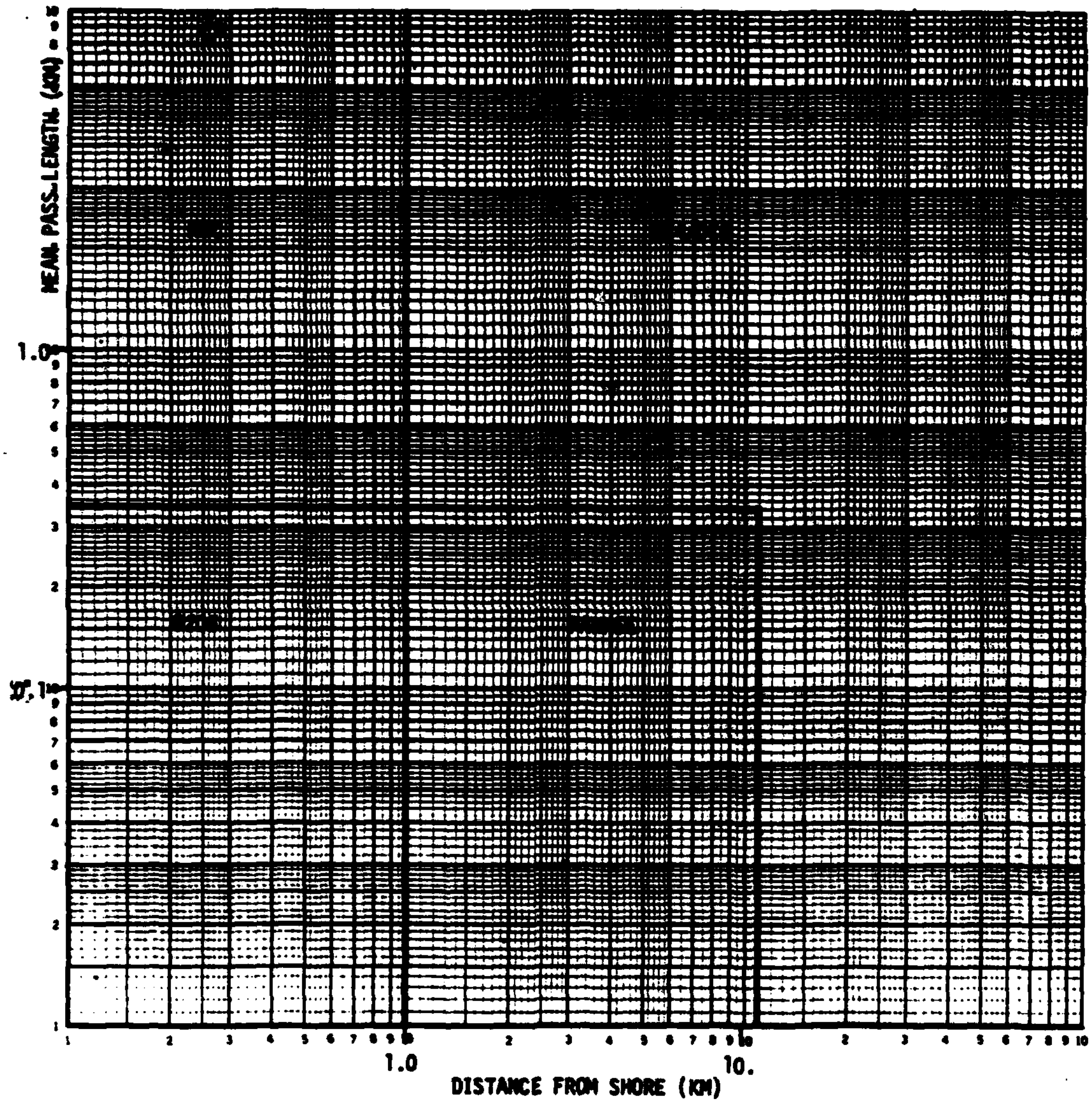

FIGURE 19. VEHICLE OF CHOICE FOR DIFFERENT OPERATING REGIMES

The other considerations in vehicle selection are availability, response time, suitability for selected dispersant, safety of crews and vehicles, and support requirements.

DC6-DC4-CL215: These are available for hire from agricultural and forest application firms, located in the western U.S. and Canada (e.g., Conair, Globe Air). Availability varies with season; a reasonable availability time for planning is 1-3 days; ferry time of about 6 hours must also be allowed, depending on spill location. The contractor supplies crews, fuel, insurance, but not dispersant. Little or no training is required since the crews are experienced in similar operations over land. Coordination techniques with the spotter aircraft, however, must be worked out. Special nozzles must be obtained in advance by contract or by purchase; time to fit the nozzles is about 30 minutes.

B206: There are large numbers of agricultural and other commercial helicopters suitable for dispersant application. The Helicopter Association of America lists about 600 members in the U.S. alone. Availability within hours is occasionally possible, but 1 day is a reasonable availability time. This time varies widely with location. Requirements with regard to crew, fuel, nozzles, and training are similar to those for large fixed-wing aircraft, described above.

HH3: The USCG HH3-F helicopter is staged at 9 locations, from which it is available on very short notice for SAR and other USCG missions:

Astoria, OR	3
Aguadilla, PR	3
Otis AFT, MA	3
Clearwater, FL	4
Elizabeth City, NC	3
Kodiak, AK	4
New Orleans, LA	3

San Diego, CA	3
Sitka, AK	3
	29

When operated in a belly-slung (two way mission) mode, it has a maximum payload of about 2500 lbs over a range of 140 n. mi. The ferry range with external payload is about twice that distance. These ranges are shown in Figure 20. The dots represent oil ports with over 1,000,000 tons of crude or heavy oil movement per year. At 60 knots, the time to maximum range is 2.33 hours for the two-way mission and 4.67 hours for the ferry flight. If the load is carried internally, the ferry range (not shown in Figure 20) is about 400 n. mi. which is almost adequate to bring a New Orleans based vehicle to Corpus Christi or a San Diego based vehicle to San Francisco. This trip takes about 3 hours.

The bucket equipment for HH3 use is typically a 300 gallon bucket with a 32 foot boom. The boom folds, yielding an envelope of about 5' x 5' x 15', which can be stowed within the HH3. Total weights are about 350 lbs empty, and 2750 lbs full. Maximum pumping rate is 100 gallons per minute (380 liters per minute).

There are three possible dispersant missions for the HH3, depending on distance from the HH3 base to the spill.

(a) Direct Two-Way. The HH3 carries the externally mounted bucket/boom outfit to the spill site, applies the dispersant and returns to the base. This mission covers about 60% of all expected oil spills. (See Figure 20 and Table 8.) The solid circles in that figure, corresponding to the 140 n. mi. range of this mission, do not encompass the major oil movement areas in New York, New Jersey, upper Delaware Bay, Calcasieu-Lake Charles, any part of Texas, or San Francisco. Response time, however is less than 3 hours from request to application.

(b) Direct One-Way. The HH3 carries the externally mounted bucket/boom outfit to the spill, applies the dispersant and lands at a nearby base. Operations are then continued from the new base, close to the spill. Response time is less than 5 hours from

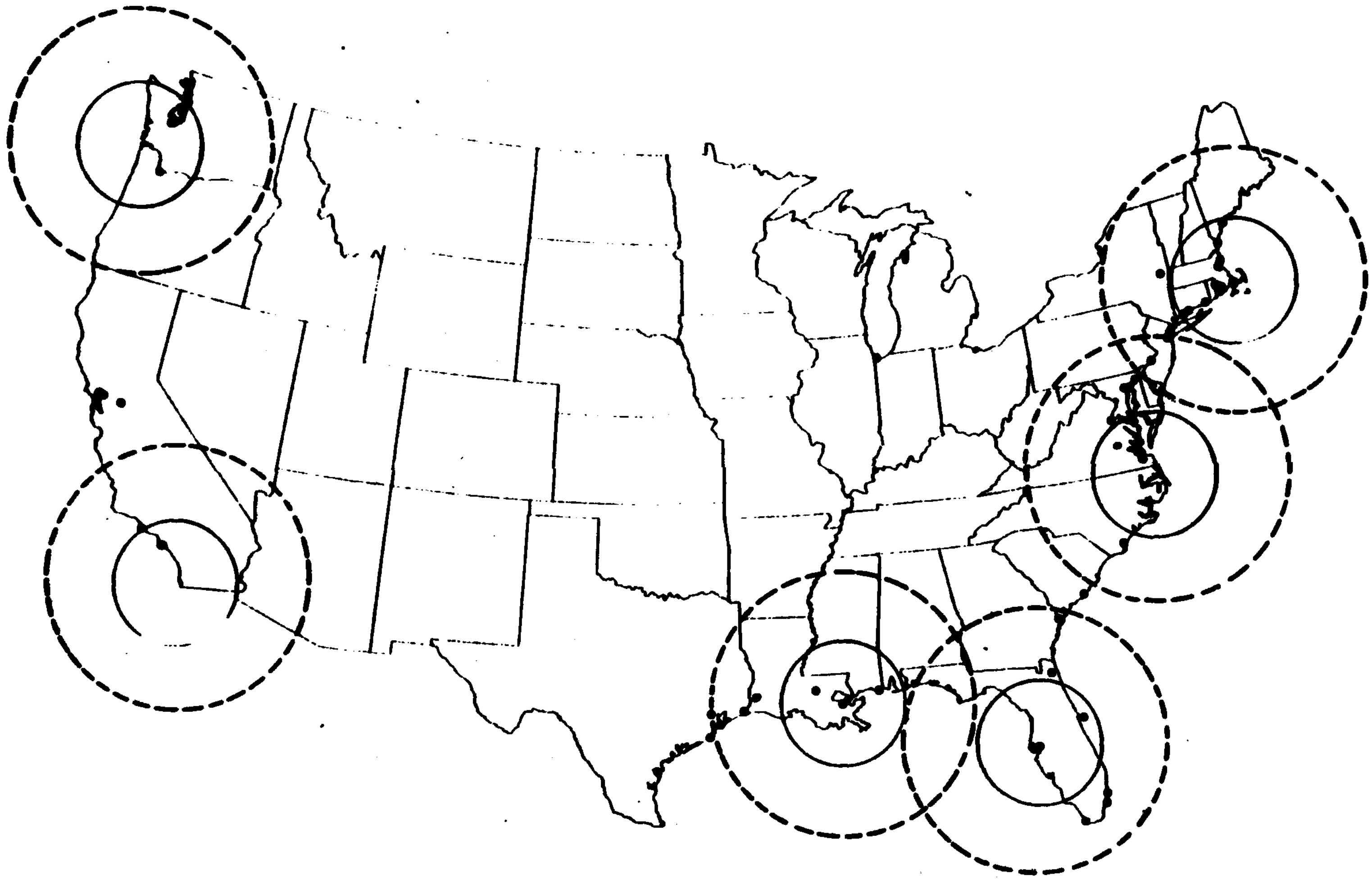

FIGURE 20. RANGES OF HH3-F WITH EXTERNAL LOAD, ONE-WAY AND TWO-WAY MISSIONS

request to application of dispersant, but maximum range is about 250 n. mi. (Dashed circles in Figure 20.) The second application is more rapid than the first, since the new base is closer to the spill, and the 5 hours required to respond may be used to bring more dispersant to the new base.

(c) One-Way Ferry. If the distance from the HH3 station to the spill is greater than 250 n. mi., but less than 540 n. mi., the mission may be accomplished by ferrying the spray equipment and dispersant internally from the HH3 station to an operations base near the spill. The HH3 is there refuelled, while the spray gear is removed, and a direct two-way externally mounted mission (as (a) above) is launched from the operations base. The total range is the sum of the ferry range and the direct two-way mission range. Total time is 6 hours or less.

Pawnee. The Piper Pawnee is typical of the small fixed-wing agricultural aircraft in the U.S. Although thousands are available, they are less available in industrialized seaports than inland. Availability times range from 1-2 hours to 1 day, depending on the spill location. The conditions regarding fuel, crew, nozzles, ferrying, and training are similar to those for the large fixed wing or B206.

2. LOCATIONS AND SIZES OF STOCKPILES

Present oil response equipment deployment is planned for eleven USCG bases. If these bases are also dispersant stockpile locations, the percentage of the total national dispersal capability that should be located at each base so as to maximize the amount of oil that can be treated directly from the closest base is given in Table 9A. These theoretical percent distributions must be modified by several practical considerations:

(a) Only a fraction of the spilled volume is amenable to dispersants.

(b) Adjacent stockpiles can be used to supplement the one closest to the spill.

(c) Associations and private companies maintain dispersant stockpiles in the U.S., as shown in Table 10.

(d) Dispersant production can supplement stockpiles in a matter of days or weeks, as shown in Table 11.

It can be seen from Table 10 that the total of U.S. stockpile sizes is greatest for concentrate (170 tons) and for water-based (167 tons) dispersants. Little water-based product is stocked in the New England or Alaska areas, however, probably because of the potential for freezing in those parts of the U.S. Concentrates or hydrocarbon-based products do not have that disadvantage.

If the entire U.S. stockpile of dispersant were available to treat any spill over 50,000 gallons in U.S. waters, then the fraction of the oil that could be treated over a series of spills could be calculated from the distribution of spill volumes (Figure 12). The result of such a calculation is shown in Figure 21, where it has been assumed that 30% of the spilled oil is available for dispersant treatment. It can be seen that present U.S. stockpiles (of the order of 200-400 tons) could treat only 4%-8% of the oil amenable to dispersal.

The concentrate dispersant stockpiles are located in Boston, Providence, Houston, Harvey LA, San Pedro CA, and Alaska (Homer, Kenai, Yakutak) as shown in Table 17 of Volume I. If only the lower 48 states are considered, the typical straight-line distance from stockpile to oil port is 260 n. mi. (Houston to N. Orleans, Boston to Philadelphia). The delivery times would be those shown in Table 12 and Figure 16 under cases 2(a) and 2(b). If the stockpile owner dedicated a semitrailer for this purpose, the delivery times would be those of cases 1(a) and 1(b). If, in addition, the Coast Guard or DOD made aircraft available for transport of the stockpiles, then the times of cases 3(a), 3(b), 4(a) and 4(b) would apply. The cases 5 and 6 do not apply unless the stockpile was located at a USCG airbase (not the case). Hence from Figure 16 one sees that the delivery times would be about 4 or 6 hours by USCG or USAF aircraft (cases 3(a) and 3(b)) and 8 or 10 hours by dedicated tractor-semitrailer (cases 1(a) and 1(b)). If the

tractor-semitrailer had to be rented, the delivery time would be 12 to 14 hours. These times bring the dispersant to the operations base; additional time would be required to apply the dispersant to the slicks. Spills at locations greater than 260 n. mi. from a stockpile would require additional time at the rate of 3 hours for each 100 n. miles over 260 n. miles for land transport and 1/3 hour for each 100 n. miles over 260 n. miles for air transport.

3. CHOICE OF DISPERSANT

The choice of dispersant is affected by the choice of application technique and stockpile locations and sizes. It is also affected by practical considerations such as cost, availability and safety of use. Although no hard choice needs to be made at this time in Coast Guard development, certain preferred operational characteristics can be stated. These characteristics narrow down the list of suitable dispersants from an operational point of view even if attention is restricted to EPA-accepted data and manufacturer disclaimers. The desirable characteristics are:

(1) Pumpability. A dispersant should be pumpable down to 20°F at least for application in the northern U.S. and 0°F in Alaska. (volume I, Table 4) Pumping cannot take place below the pour point or below the freezing point. Only hydrocarbon-based and concentrate products have pour points below 0°F; water-based products cannot be employed in northern locations because of freezing. Since a stockpile should be available for transport and use in any part of the country, water-based dispersants are at a disadvantage.

(2) High Flash Point. Only one of the thirteen dispersants covered by the EPA-accepted data of Volume I presented a flash point substantially less than 150°F.

(3) Low Temperature Storage Stability. A suitable dispersant should undergo no adverse changes when stored for prolonged periods at low temperatures (say, 20°F in northern

lower 48 states, 0°F in Alaska). The available data are inadequate to determine storage stability completely for all products submitted, but the data submitted to the EPA on "minimum storage point" show 4 products above 20°F, and 7 products above 0°F.

(4) Shelf Life. Although shelf life requirements will depend on many factors, the UK specification of 5 years may be taken as a reasonable nominal point.

(5) Aerial Application. Since aerial application achieves much higher rates at lower cost than vessel application, it is almost essential that any dispersant be capable of effective dispersion when applied by air. This implies

(a) Agitation not essential: The manufacturer's requirements for agitation can be accepted at a minimum. Those dispersants requiring vigorous agitation after application are considered unsuitable for aerial application.

(b) No mixing required: Dispersants that must be mixed with large volumes of water (more than 20:1) at time of application are unsuited for aerial application.

(6) Effectiveness. This has several facets relevant to operations, none of which are covered by EPA-accepted data. Hence, effectiveness is not one of the relevant characteristics.

(7) Fresh water use. This is a desirable but not an essential characteristic. Manufacturer's disclaimers are acceptable data.

(8) Significant stockpiles. "Significant" is here taken arbitrarily to mean total U.S. stockpiles of 100 or more 55-USG drums as of February 1980.

(9) Significant production. This is taken as production capability of 100 or more 55-USG drums per day in the U.S. with a production lead time of 1 day or less, as of February 1980.

The logistics-related characteristics of 13 dispersants with data accepted by EPA are shown in Table 17. An x indicates that the product is undesirable relative to the characteristic, a ✓ indicates, that it is desirable from that point of view. A blank indicates either no data, or not applicable. The chart is based on EPA-accepted data or on manufacturer's disclaimers. The Pour Point and Storage Point characteristics have two levels of desirability: 0°-20°F for use in the U.S. outside of Alaska, and <0°F for use in Alaska.

From Table 17 it appears that no product has all desirable properties. Moreover, the all-important characteristics of effectiveness are not shown or fully known. However, the question of effectiveness on various crude oils, under given agitation, temperature and slick conditions are answered partly by British and Canadian tests, which cover four of the thirteen products. The results (Volume I) may be summarized as follows:

Doe (Reference 10) conducted tests in a simulated environmental tank. He defined effectiveness as the dispersant oil ratio required to disperse 65% of the test oil. He used both fresh and seawater at various temperatures. The results are:

Product No.	Temperature °C	Effectiveness on VC/S	MB/S	HB/S	VC/F
4	15	IE	-	-	IE
9	1	1:27	IE	IE	1:10
11	5	1:1	IE	-	1:3
12	5	1:27	1:1	-	1:1

where VC = Venezualian Lago Media Crude, MB = Medium Bunker Fuel, HB = Heavy Bunker Fuel, S = salt water, F = fresh water, and IE = Ineffective.

TABLE 17. DISPERSANT SELECTION CHART BASED ON LOGISTICS-RELATED PROPERTIES

	Product Number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1. Pour Point													
>20°F			x		x	x	x	x					
0°-20°F	✓	✓		✓									
<0°F									✓	✓	✓	✓	✓
2. Flash Point >150°F	✓	✓	✓	x	✓	✓	✓	✓	✓	✓	✓		✓
3. Storage Point (min)													
>20°F					x		x		*			x	
0°-20°F	✓			✓		✓					✓		
<0°F		✓	✓							✓			✓
4. Shelf Life													
>60 mos	x	✓	x	✓	x	✓	x	✓	✓	✓	✓	✓	✓
5. Aerial Application													
No Agitation					x		x	x			x	x	x
No Mixing						x		x					
6. Fresh Water Use	✓		✓		✓	✓	✓	✓	x				
7. Stockpiles	✓	x	x	x	✓	✓	x	✓	✓	x	x	x	✓
8. Production	✓	✓	✓	✓	x	✓	x	✓	✓	✓	x	x	x

*EPA data disagree with manufacturer's literature on minimum storage point.

✓Indicates that the product is desirable with regard to the property

xIndicates that the product is undesirable with regard to the property

Blank indicates no data or not applicable.

Table based EPA provided data, manufacturer's claims or disclaimers and criteria discussed in text.

Gill (Reference 11) conducted sea trials to determine the average end-point ratio of oil/dispersant using Tia Juana crude. The results are:

Product No.	Temperature °F	End Point on Tia Juana Crude
9	62	8.5
11	62	2.9
12	62	7.8
9	40	-
11	40	2.3
12	40	6.0

If all attention is restricted to these four products, dispersant selection is almost immediate: Product 4 not only shows poor effectiveness in Doe's data, but has a very low flash point and no U.S. stockpile; Products 11 and 12 have neither production nor stockpiles in the U.S. and require agitation, although Product 12 has been used in aerial tests (see Volume I). The remaining product (#9) appears to have a high storage temperature and is not recommended by the manufacturer for fresh water use. (Both of these points required clarification; the first is inconsistent with pour point and manufacturer data, the second with Doe's data.)

The conclusions to be drawn, then, are that

- o No product has all desirable logistics-related characteristics
- o Relevant effectiveness data have been published for only four of the 13 dispersants at the present time (September 1980). Two of these (products 9 and 12) bear further investigation of their logistics-related characteristics (storage, fresh water use, aerial application)

4. FORMULATION OF STRATEGIES

The preceding results regarding vehicles, stockpiles and dispersants need to be combined into practical strategies for Coast Guard implementation. The major strategic question is the extent

and nature of Coast Guard capability to employ dispersants. Five levels of capability will be formulated in this section. In the next section they will be evaluated with regard to response time, response effectiveness, cost of dispersal, USCG equipment and training costs, and implementation time.

4.1 STRATEGY O: PRESENT CAPABILITY PLUS EXERCISES

At the present time there exists some commercial and private capability to deliver and apply dispersants if and when approval is received. This has actually occurred twice, both cases in New York Harbour (Dredge Pennsylvania, Sea Speed Arabia). Under present circumstances dispersant application is dependent on the availability of commercial aircraft and dispersants. Generally, these are not under long-term contract to the Coast Guard; contractual arrangements must be made at the time of the spill. Rapid response depends on aggressive action by the OSC or by contractors or by the EPA.

In the event of a large off-shore spill, delivery of suitable fixed wing aircraft can involve delays of several days. Further, the use of existing aircraft capability may be delayed if the proper nozzles are not on hand. This is not unlikely, since the droplet size required for dispersants is much larger than normally employed for agricultural spraying.

Another deficiency of the present capability is the lack of "spotter" training. The "spotter" directs the application vehicle(s) from about 1000 ft altitude via air/air radio; although this skill may be acquired on the spot, it is preferable to have either USCG or contractor personnel available who are familiar with the techniques. It is also advisable for the pilot of the application vehicle to have previous experience or training in working under spotter control. Under the present conditions, no organized familiarization sessions are carried out. Under Strategy O, the MSO/COTP at each of the 11 pollution response sites of Table 8 would carry out an annual small aircraft spraying exercise of about 3 days duration, involving two spray aircraft (one fixed

wing, one helicopter) and one spotter vehicle. This would allow one day's exercise with each aircraft type, plus one day of simultaneous operation. In addition, the base would procure and stock one set of nozzles for each spray aircraft, plus spares. Two full-time USCG personnel (one pilot, one pollution response officer) would provide training on a rotating basis throughout the country.

The zero-level strategy is well suited to current conditions, under which dispersant use is rarely approved.

4.2 STRATEGY 1: COMMERCIAL CONTRACTING

This strategy involves standing basic ordering agreements with commercial organizations executed by MSO or COTP offices, for use by the OSC. It is assumed that 11 offices nearest the sites listed in Table 9 each carry out the strategy as follows (see Table 18):

1. Small fixed wing or helicopter aircraft of at least 100 gallon capacity equipped with suitable nozzles (see Volume I), to be available at the relevant USCG station within a specified time. The delivery time and number of aircraft would vary with local conditions but 1 to 2 small fixed wing aircraft available from each contractor in 12-24 hours is not an unreasonable goal of negotiation. Helicopters such as the B206 are not always available on short notice; a one-day availability is common. Both fixed wing and helicopters should be contracted for since they are suitable for different regimes (see Figure 19). These should be "wet" contracts, i.e., they should include dispersant, because (a) the contractor is usually better able to store dispersant than the MSO, (b) it will generally reduce the response time, since loading can be done more rapidly by the contractor using his own facilities. The Coast Guard, of course, must specify the dispersant. Enough dispersant should be stockpiled by the contractor in 55 USG drums for 20 sorties of each aircraft. (This is about 11,200 liters

TABLE 18. STRATEGY 1 DEPLOYMENT

	Contractors		
	SFW	SHC	Drums
Boston	2	2	70
New York	2	2	70
Philadelphia	2	2	70
Norfolk*	2	2	70
Miami	2	2	70
New Orleans**	2	2	70
Galveston	2	2	70
Los Angeles	2	2	70
San Francisco	2	2	70
Seattle	2	2	70
Kodiak	2	2	70

Nationally available: 3 large fixed wing, DC4 or DC6

Dispersant Manufacturer Plants: 100 tons

*MSO closest to Elizabeth City.
**MSO closest to Bay St. Louis.

for the Pawnee, and 6,000 liters for a Bell 206B, enough for 1 day's operation.) However, in order to reduce dispersant costs, if more than one aircraft of each type is contracted, the stockpile should be distributed among contractors for the type, with provision for truck transport to the operations base when needed. Storage temperature and conditions must be specified as well. If a Coast Guard helicopter is not stationed at the base, the contracts should call for at least one spotter aircraft, available at the same time as the spray vehicle.

2. Periodic training exercises. These should be part of the local contingency plan, and should involve EPA as well as Coast Guard and contractor personnel. In addition to local contracts, national contracts servicing all MSO/COTP areas would be negotiated as follows (see Table 18):

3. Large fixed-wing aircraft such as DC-4 or DC-6 equipped with suitable nozzles to be able at pre-selected operations bases within specified times. While full-year 24-hour retainer fees are high (see Table 4B) a more reasonable service charge is usually levied for 1 to 3 day delivery. Standing as-required contracts should be negotiated with as many firms as possible (i.e. with both Globair and Conair) so as to obtain minimum available delivery time. The contracts should include crews and fuel, but no dispersant i.e., 'dry'.

4. Dispersant purchase orders from the manufacturers. If it is assumed that the dispersant of choice is domestically stored concentrate (product 9) then the stockpiles presently available amount to about 170 tons, or enough to treat about 3.4% of the "dispersable" oil. (To this must be added the amount of dispersant stored under local 'wet' contracts, plus amounts that can be produced). Contracts should provide a standing order of a minimum of 100 tons of dispersant in 55-USG drums delivered by truck

to designated airports in the U.S. These airports would be selected to be near the manufacturer's supply and also accessible by C141 and C130 aircraft. The latter would be supplied by USAF and USCG. The transport times from airport to operations base are given in Figure 16, curve 3(a). The C130 can accommodate 48 to 64 drums (9 to 12 tons) per aircraft and the C141 can accommodate 80 to 160 drums (15 to 30 tons). A 100-ton total stockpile can be moved from 4 locations in less than 24 hours to most U.S. destinations. Use of commercial carriers for this operation will probably result in greater cost to the government because of the fixed overhead on C131 and C141 vehicles.

The strategy just outlined provides capability to deliver dispersants to a slick with minimum USCG commitments of about $500K plus about $300K per year, as will be seen in the following section. The major part of this cost is for dispersant stocked with the small aircraft contractors. The amount of these stocks (20 sorties worth) is designed to allow about 10 hours of operation, which would carry the operations until the day following initiation. If required, large fixed wing aircraft would be ready for use from 1 day to 3 days after initiation. Therefore, reduction in dispersant stockpiles would run the risk of interruption in application, unless provision were made for rapid transport of the adjacent base stockpile to the spill base. This is the basis of strategy 1A, to be described next.

4.3 STRATEGY 1A: COMMERCIAL CONTRACTS PLUS USCG STOCKPILES

This strategy is identical to Strategy 1 except that the small aircraft contracts do not include dispersant, i.e., they are 'dry', and the USCG maintains the equivalent stockpiles at or near each of the eleven bases. These stockpiles would be ready for immediate transport to an adjacent base (except for the Kodiak

stockpile). The average travel time between base pairs in the 48 states is 10.7 hours, which brings delivery to about 12 hours, assuming pre-loaded tractor-trailers.

With the assumption of USCG-owned and maintained stockpiles at the 11 bases, each stockpile of 70 drums can be reduced by half. But storage costs and transport costs would be added. A 35-drum stockpile easily fits on one low-bed semitrailer with a pump for aircraft loading. It will be assumed that at least one tractor is available for pollution response at each base. The low-bed semi-trailer, however, would have to be purchased and pre-loaded with dispersant; estimated cost of semi-trailer is \$7500. Storage space (heated) is estimated at \$2000 per year, off-base. The reduction in initial cost will be seen to be about \$150K, over 11 bases, but the annual cost will increase by \$22K per year.

Both Strategy 1 and 1A involve an outlay of Coast Guard funds of sufficient magnitude that the projected frequency of use of dispersants becomes an important factor in strategy selection.

4.4 STRATEGY 2: COMMERCIAL CONTRACTING PLUS USCG HH3-F

The availability and response times of the USCG HH3-F are generally superior to those of commerical contractors of small fixed and rotary wing vehicles. Normalized application costs are comparable. In this strategy, the USCG HH3-F would be employed instead of commercial contracts within the 250 n. mi. range of the Direct One-Way mission. These areas are enclosed in the dashed circles of Figure 20. This would eliminate all commercial contracts at the eleven spill response bases of Table 9 except those of San Francisco. Supplementary contractors may be arranged for Corpus Christi TX and Honolulu HI for complete coverage of the U.S. (see Table 19).

This strategy, however, does not reduce the requirements for stockpiles at the 11 bases. The stockpiles for 1 day's operation of the HH3-F is about 15,000 liters (70 drums) under good slick

TABLE 19. STRATEGY 2 DEPLOYMENT

	USCG		Contractors		
	HH3-F[1]	Drums[2]	SFW[3]	SHC[4]	Drums[5]
Boston	0	70			
Otis AFB	2	3			
New York	0	70			
Philadelphia	0	70			
Elizabeth City	2	70			
Miami	0	70			
Aguadilla	2	70			
Clearwater	2	70			
New Orleans	2	70			
Galveston	0	70			
Corpus Christi	0	0	2	2	70
San Diego	2	70			
Los Angeles	0	70			
San Francisco	0	0	2	2	70
Astoria	2	3			
Seattle	0	70			
Kodiak	2	3			
Anchorage	0	70			
Sitka	2	70			
Honolulu	0	0	2	2	70

Nationally available: 3 Large Fixed Wing Aircraft

Dispersant Supplier Plants: 100 tons dispersant

(1) Assumed available for pollution response.
(2) Pre-mounted on 40 ft semi-trailer; 55 USG each.
(3) Small Fixed Wing, such as Piper Pawnee.
(4) Small Helicopter, such as Bell 206B.
(5) Assumed to be stored on contractor premises in transportable 55 USG drums.

conditions (Figures 4 through 7), somewhat more than for the Piper Pawnee's 11,200 liters, so that the stockpiles at the 11 bases would be greater _in toto_. In addition, stockpiles would be placed at Clearwater FL, Aguadilla, PR, San Diego, CA, and Sitka, AK. The Bay St. Louis stockpile would be located at New Orleans and the Los Angeles stockpile at San Diego. Each stockpile (about 70 55-USC drums) would be transportable by a single 40 foot semi-trailer or by two low-bed trailers. Single-mission (3 55-USG-drum) stocks would be located at Otis AFB, Kodiak, AK, and Astoria, OR.

The requirement for training exercises would be met in much the same way as in Strategy 1, except that contract equipment and personnel would not be involved except at San Francisco, Corpus Christi, and Honolulu. The nine USCG HH3-F bases would each exercise once/year, two helicopters being involved in each exercise. One full time training team of two men would circuit the nine bases once per year, spending one month to train 2 men at each base. The other three months would be employed to train the three contractors.

The large fixed-wing aircraft and dispersant purchases from the manufacturer would be the same as in Strategy 1.

4.5 STRATEGY 2A: CONTRACTS PLUS USCG HH3-F (REDUCED)

The deployment of Strategy 2 can be reduced so as to make its coverage comparable to that of Strategy 1. This is done in Table 20. USCG stockpiles are eliminated at Aguadilla, and Sitka; they are reduced at Clearwater and San Diego; contractors are eliminated at Corpus Christi and Honolulu; HH3-F support is removed at Aguadilla and Sitka. These reductions are reflected in lower stockpile costs and lower training cost.

4.6 STRATEGY 3: CONTRACTS USCG HH3-F, 1000-TON USCG STOCKPILE

This strategy is the same as Strategy 2, except that commercial manufacturer's stockpiles are supplemented by a large-scale USCG stockpile. As seen in Figure 21, a total of 2,500 tons

TABLE 20. STRATEGY 2A DEPLOYMENT

	USCG		Contractors		
	HH3-F(1)	Drums(2)	SFW(3)	SHC(4)	Drums(5)
Boston	0	70			
Otis AFB	2	3			
New York	0	70			
Philadelphia	0	70			
Elizabeth City	2	70			
Miami	0	70			
Clearwater	2	3			
New Orleans	2	70			
Galveston	0	70			
San Diego	2	3			
Los Angeles	0	70			
San Francisco	0	0	2	2	70
Astoria	2	3			
Seattle	0	70			
Kodiak	2	3			
Anchorage	0	70			

Nationally available: 3 Large Fixed Wing Aircraft

Dispersant Manufacturer Plants: 100 tons.

(1) Assumed available for pollution response.

(2) Pre-mounted on 40 ft semi-trailer; 55 USG drums.

(3) Small Fixed Wing, such as Piper Pawnee.

(4) Small Helicopter, such as Bell 206B.

(5) Assumed to be stored on contractor premises in transportable 55 USG drums.

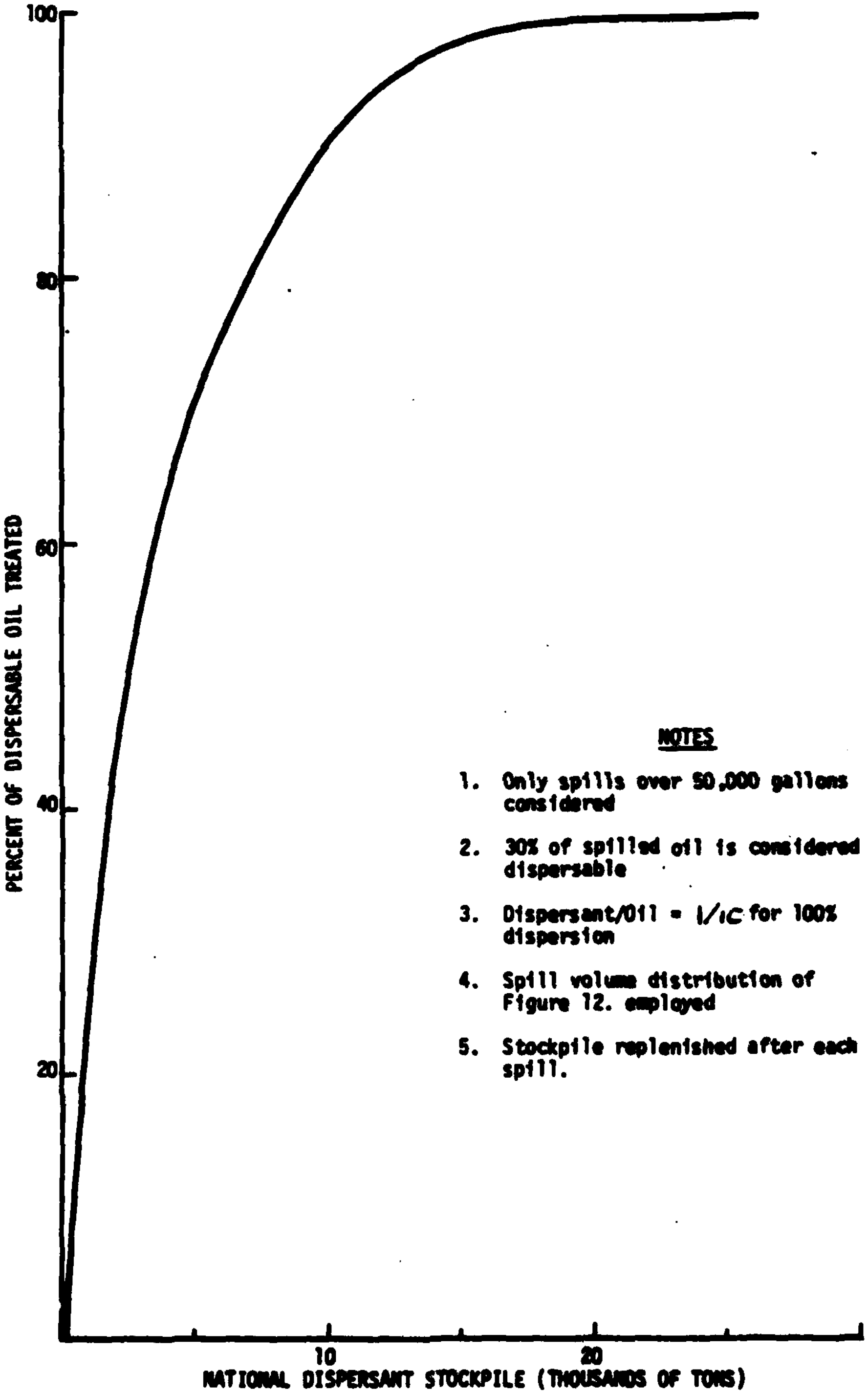

FIGURE 21. PERCENT OF DISPERSABLE OIL THAT CAN BE TREATED AS A FUNCTION OF SIZE OF STOCKPILE

(13,500 55-USG drums) would be required to treat one half of the dispersable oil from spills over 50,000 gallons, assuming the stockpile was immediately replenished after each use. This amount of dispersant corresponds to a single release of about 83,000 tons of oil, assuming a 1:10 dispersant:oil ratio and 30 percent dispersable fraction. The cost of the stockpile would be about $8.3 million, assuming a concentrate is employed, and would take about one month to manufacture. Strategy 3 is based on a reduced stockpile of 1,000 tons of concentrate, which is enough to treat 20 percent of the oil in spills over 50,000 gallons, or a single spill of 33,000 tons. Even with this reduced goal, however, the stockpile would be about $3.3 million at dispersant prices of $11 per gallon. This cost is an unavoidable consequence of the assumptions on effectiveness ratio and dispersable fraction, which result in a concentrated dispersant cost of $100 per ton of oil spilled. (At this rate, the dispersant itself would have cost $2.5 million to treat the Argo Merchant release.)

It may be noted, by way of comparison, that the present U.K. stockpile of dispersants is equivalent to about 16,500 55-USG drums, or 3,000 tons.

Transport of 1,000 tons of dispersant in 55-USG drums would require 34 C141 trips (at 2500 n. miles each), OR 85 C130H trips (at 1000 n. miles each), OR 114 C130B trips (of 500 n. miles each). Response times are given in Figure 16. Commercial transport costs would be about $200 per 55-USG drum over 1000 n. miles, or $1 million for the entire 1000-ton stockpile. (See "FACTORS IN DISPERSANT STOCKPILING")

The use of government transport aircraft would reduce delivery time to 4-8 hours, i.e., the first shipments would reach the operations base in that time. This would be well in advance of the arrival of large fixed-wing aircraft, which cannot be expected sooner than 1 to 3 days after order without a retainer. Retainer fees for DC4 are about $120K/year. This is only 4 percent of the dispersant cost and would reduce delivery time of the aircraft from 1-3 days to 4-8 hours, as required. A single DC4 on retainer,

therefore, would provide excellent response to a large spill until more large fixed-wing aircraft can be contracted.

The large financial commitment implied in this strategy makes it practical only if EPA policy regarding the use of dispersants is such as to make their widespread use likely. In particular, the likelihood of dispersant use on large-size (10,000-100,000 tons) crude oil spills would have to be ascertained because the major investment in Strategy 3 is in dispersant stockpiles required for such spills.

Stockpiling of 1,000 tons of dispersant by the U.S. Coast Guard, in addition to the deployment of Strategy 2, will be designated as Strategy 3.

STRATEGY 3A. If the 1,000 ton stockpile is added to Strategy 2A, there results Strategy 3A.

STRATEGY 4: Contracts, USCG HH3-F, and 2,500 TON USCG Stockpile. If the USCG-owned stockpile in Strategy 3 is set at 2,500 tons of dispersant, then there results Strategy 4.

5. EVALUATION OF STRATEGIES

The strategies just outlined will be evaluated with regard to response time, initial and annual cost, cost per spill, and implementation time.

Initial and Annual Costs

For purposes of estimation, dispersant costs will be taken to be $11 per USG, corresponding to current (September 1980) prices for domestically produced concentrate. The costs to be estimated are the incremental costs over presently planned expenditures for pollution response. In particular, they will be calculated on the assumption that 11 USCG pollution response bases will be established as in Table 9, and that USCG aircraft will be maintained for other missions as well as pollution response. USCG aircraft costs will be included only for dispersant-specific missions and training. Dispersant storage is calculated at $5/square foot up to 5,000 square feet, and $2.50/square foot above that. The costs of the various strategies are shown in Table 21.

TABLE 21. INITIAL AND ANNUAL COSTS FOR STRATEGIES 0 THROUGH 4

Type	Size	Source	Availability Time	Number	Initial Cost	Cost per Yr.	USCG M-Y/year
STRATEGY 0: PRESENT CAPABILITY PLUS EXERCISES							
Exercises	3-day	USCG	-	11/yr	$0K	$275K(1)	4
STRATEGY 1: COMMERCIAL CONTRACTS							
Fixed Wing	Small	Contract(2)	6-24 hr	22	0	0	0
Helicopter	Small	Contract(2)	12-24 hr	22	0	0	0
Fixed Wing	Large	Contract	1-3 days	3	0	0	0
Dispersant	11,200 l.	Contract(2)	1-2 hr	11	360	0	0
Dispersant	3,400 l.	Contract(2)	1-2 hr	11	110	0	0
Dispersant	100 tons	Contract	2-4 days	1	0	0	0
Exercises	3-day	USCG	-	11/yr	0	275	4
					470	275	
STRATEGY 1A: COMMERCIAL CONTRACTS PLUS USCG STOCKPILES							
Fixed Wing	Small	Contract(2)	6-12 hrs	22	0	0	0
Helicopter	Small	Contract(2)	12-24 hr	22	0	0	0
Fixed Wing	Large	Contract	1-3 days	3	0	0	0
Dispersant	7,320 l.	USCG	1-12 hr	11	317(4)	22(3)	0
Dispersant	100 tons	Contract	2-4 days	1	0	0	0(5)
Exercises	3-day	USCG	-	11/yr	0	275	5
					317	297	
STRATEGY 2: CONTRACTS PLUS USCG HH3-F							
HH3-F	Medium	USCG	1-5 hours	18	126(6)	0	0
Fixed Wing	Small	Contract(2)	6-24 hours	6	0	0	0
Helicopter	Small	Contract(2)	12-24 hours	6	0	0	0
Fixed Wing	Large	Contract	1-3 days	3	0	0	0
Dispersant	15,000 l.	USCG	1-6 hours	14	612	28	1

TABLE 21. INITIAL AND ANNUAL COSTS FOR STRATEGIES 0 THROUGH 4 (CONTINUED)

Type	Size	Source	Availability Time	Number	Initial Cost	Cost per Yr.	USCG M-Y/year
STRATEGY 2: CONTRACTS PLUS USCG HH3-F (CONTINUED)							
Dispersant	620 l.	USCG	1 hr	3	5	0	0
Dispersant	11,200l.	Contract (2)	1-2 hr	3	98	0	0
Dispersant	3,440 l.	Contract (2)	1-2 hr.	3	30	0	0
Semitrailer	40 feet	USCG	0 hrs	14	140	0	0
Dispersant	100 tons	Contract	2-4 days	1	0	0	0
Exercises	3-day	USCG	-	9/yr	0	216	3.
Exercises	3-day	USCG	-	3/yr	0	75	0.5
					1011	319	4.5
STRATEGY 2A: CONTRACTS PLUS USCG HH3-F (REDUCED)							
HH3-F	Medium	USCG	1-5 hrs	14	98 (6)	0	0
Fixed Wing	Small	Contract (2)	6-24 hr	2	0	0	0
Helicopter	Small	Contract (2)	12-24 hr	2	0	0	0
Fixed Wing	Large	Contract	1-3 days	3	0	0	0
Dispersant	15,000 l.	USCG	1-6 hrs	10	437	20	1.
Dispersant	620 l.	USCG	1 hr	5	8	0	0
Dispersant	11,200 l.	Contract (2)	1-2 hr	1	33	0	0
Dispersant	3,400 l.	Contract (2)	1-2 hr	1	10	0	0
Semitrailer	40 ft	USCG	0 hr	10	100.	0	0
Dispersant	100 tons	Contract	2-4 days	1	0	0	0
Exercises	3-day	USCG	-	7/yr	0	168	3
Exercises	3-day	USCG	-	1/yr	0	25	0
					686	213	4

TABLE 21. INITIAL AND ANNUAL COSTS FOR STRATEGIES 0 THROUGH 4 (CONTINUED)

Type	Size	Source	Availability Time	Number	Initial Cost	Cost per Yr.	USCG M-Y/year
STRATEGY 3: CONTRACTS, USCG HH3-F, AND 1000 TON USCG STOCKPILE							
This strategy encompasses all items of Strategy 2, plus							
Dispersant	1000 tons	USCG	4-8 hrs	-	3,300.	50	1
Fixed Wing	Large	Retainer	4-8 hrs	1	0	120	0
			Totals from Strategy 2:		1,011	319	4.5
					4,311	489	5.5
STRATEGY 3A: CONTRACTS, USCG HH3-F (REDUCED), and 1000 TON USCG STOCKPILE							
This strategy encompasses all items of Strategy 2A, plus							
Dispersant	1000 tons	USCG	4-8 hrs	-	3,300	50	1
Fixed Wing	Large	Retainer	4-8 hrs	1	0	120	0
			Totals from Strategy 2A:		686	213	4
					3,986	383	5
STRATEGY 4: CONTRACTS, USCG HH3-F, AND 2,500 TON USCG STOCKPILE							
This strategy encompasses all items of Strategy 2, plus							
Dispersant	2500 tons	USCG	4-8 hrs	-	8,250	125	1
Fixed Wing	Large	Retainer	4-8 hrs	1	0	120	0
			Totals from Strategy 2:		1,011	319	4.5
					9,261	564	5.5

NOTES TO TABLE 21.

(1) Based on 12 hours small fixed wing, 12 hours small helicopter, 24 hours HH3-F; see Table 4B.

(2) Contract includes aircraft and dispersant for 20 sorties. Contract cost taken to be equal to dispersant cost plus actual aircraft time. Dispersant storage is assumed to be a no-charge condition of contract.

(3) Storage cost.

(4) Dispersant plus semi-trailer.

(5) Two full time travelling trainers, 3 trainees per base, one month each per year.

(6) Cost of bucket spray gear.

Response Times

Response times are limited by aircraft availability, dispersant stockpiles, dispersant delivery capability, and dispersant production capability. Two cases are distinguished: (1) small aircraft response employed for small spills and the initial phases of large spills, and (2) large aircraft response to large spills. Typical scenarios for these are shown in Figure 22.

Small Aircraft Response: In Strategies 1 and 1A the initial small aircraft capability is assumed to be provided by one fixed-wing (Pawnee) aircraft, available at 6 hours. It applies dispersant from the contractor stockpile at the rate of 11,200 liters per 10-hour day. At the 12th hour of the operation (10.2 days) it is supplemented by one small helicopter (Bell 206B), which brings the application rate to 14,640 liters per day, until the dispersant available to the Pawnee contractor is exhausted, at 1.6 days. Application then proceeds by helicopter alone at 3,440 liters per day until 2.2 days, at which time both contractor supplies of dispersant (14,640 liters) are exhausted. In Strategy 1A one half of the dispersant is owned and stored by the Coast Guard at the local base, and the second half of the 14,640 liters is brought by tractor-trailer from the neighboring base. This allows both fixed wing and helicopter to continue at full rate until the supply is exhausted at 1.75 days.

In Strategies 2, 2A, 3, 3A, and 4, the Coast Guard HH3-F is assumed to be available in 1 hour for all 20 bases except Corpus Christi, San Francisco, and Honolulu in Strategies 2, 3, and 4, and for all 16 bases except San Francisco in Strategies 2A and 3A. (Scenarios for the excepted bases are similar to those under Strategies 1 and 1A.) The application proceeds at the rate of 15,000 liters per day by the HH3-F for 1 day.

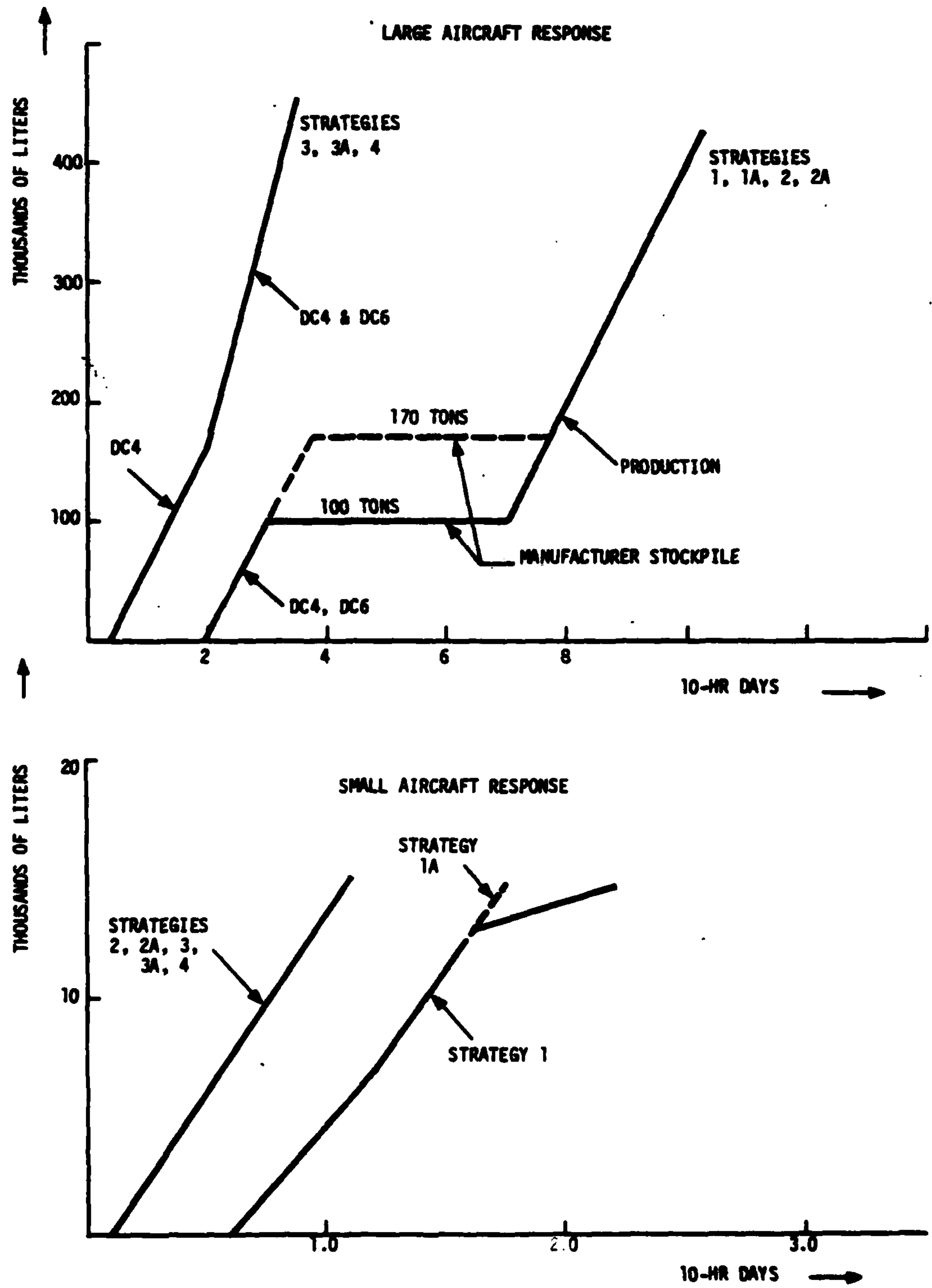

FIGURE 22. DISPERSANT DELIVERY SCENARIOS FOR LARGE AND SMALL AIRCRAFT

Large Aircraft Response: In Strategies 1, 1A, 2, and 2A the start of large aircraft operations is assumed to occur at 2 days, due to delivery of the dispersant at that time from manufacturer's stockpiles. These stockpiles are assumed to be 100 tons, but may be up to 170 tons (Table 10, concentrate). This larger figure is shown as a dashed line. At the 7th day the effect of production is seen as application by one DC4 or one DC6 continues at 100 tons per day. The application rate is limited not by aircraft availability, but by the production rate.

In Strategies 3, 3A and 4, the initial application starts at 4 hours with the single DC4 under USCG retainer, operating from the 1000-ton or 2500-ton USCG stockpile. It is supplemented by one contracted DC6 or DC4 aircraft at 2 days, which increases the application rate from 100 tons per day to 200 tons per day. Greater rates can be achieved by contracting more large fixed-wing aircraft. It is not expected that more than 3 would be needed for any one spill, and in most cases the single DC-4 under retainer would be adequate.

The superior small aircraft dispersant delivery for Strategies 2, 2A, 3, 3A and 4 is due to the rapid availability assumed for the HH3-F. In the large aircraft case, Strategies 3, 3A and 4 are superior because of both the DC-4 on retainer and the USCG stockpile.

A 1000-ton stockpile would last 10 days with only the DC-4 and 6.2 days if it were joined by another DC-4 or DC-6 on the second day. Therefore, if production quantities become available on the seventh day, only a brief interruption, if any, would occur, but application rates would be limited to about 100 tons per day by production after the 7th day. The need for the second aircraft, then, is marginal with a 1,000-ton stockpile.

If the 2500-ton stockpile is available, however, application can proceed at 200 tons per day assuming two aircraft from the second to the twentieth day, when it would be limited by production

to 100 tons per day. Thus, after the 20th day, only one aircraft would be required, although the second would probably be held on retainer as backup.

The application tonnage achievable by two large aircraft under Strategies 3, 3A and 4 are illustrated in Figure 23.

Cost per Spill

The cost per spill is determined primarily by the spill size and by the application vehicles employed, and secondly by distance from base to slick, mean pass length, areal density and slick/pattern ratio. Two cases will be assumed:

	Small Spill	Large Spill	
Volume	200	20,000	thousand liters
Distance	5	50	km
Vehicles	SFW, SHC	LFW	
Pass Length	0.6	4.0	km
Areal Density	45	45	liters/hectare
Slick/Pattern	0.5	0.5	
Dispersant Cost	11.00	11.00	$/gallon
Dispersant Vol.	6,000	600,000	

If the small spill is treated by a Pawnee or Bell 206B, the costs would be:

	Pawnee	Bell
aircraft rental (spray)	$3,000	$11,100
aircraft rental (spotter)	3,000	11,100
aircraft ferry	200	350
aircraft overnight retainer	0	1,800
dispersant at $11/USG	17,490	17,490
	$23,690	$41,840

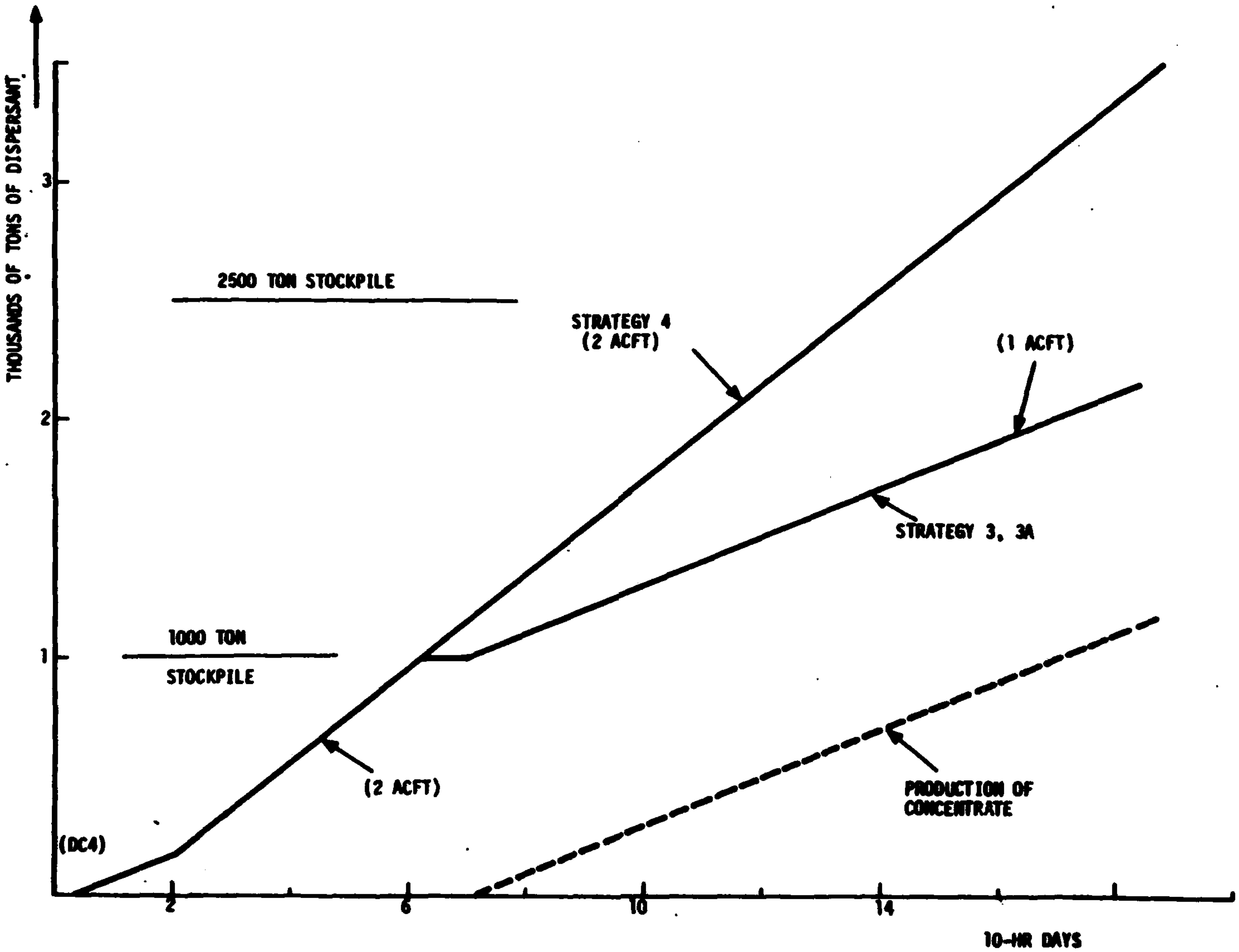

FIGURE 23. LARGE AIRCRAFT DISPERSANT DELIVERY SCENARIOS STRATEGIES 3, 3A AND 4

The dispersant costs would be incurred to replenish the contractor or USCG stockpiles. The costs of USCG and support personnel are not included. In practice the spill may be treated partly by each aircraft, so that the cost would be between $21,000 and $29,000. The spotter is assumed to be a contractor vehicle of the same type as the spray vehicle. If USCG aircraft are used for spotting, this cost would be different (not necessarily less).

If the large spill is treated by a contracted DC6 (not on retainer) the costs are estimated as follows:

Aircraft Type Time on Site	DC4 8.6 days
aircraft ferry (3 hrs each way)	$9,900
aircraft rental (spray)	144,000
aircraft overnight retainers	38,000
dispersant at $11/USG	1,749,000
spotter aircraft	43,000
transport of dispersant*	58,000
	$2,041,900.

(*$200/drum over 1000 n. mi. See text preceding.)

The spotter aircraft is assumed to be a USCG HH3-F. In this case, it is less expensive than the B206 or Pawnee because it does not require a retainer. Again, the dispersant cost is that of replenishing the stockpile, under Strategy 3, 3A, and 4, or of purchasing directly from the manufacturer under Strategy 0, 1, 2, 2A.

Implementation Time

The various strategies differ in the length of time required to plan, purchase, produce and deliver the equipment and to achieve full training capability. Table 22 shows the implementation time for the various strategies. Times are measured from start of program, and do not include program planning time or budget cycle times.

It is possible, of course, to mix strategies.

TABLE 22. IMPLEMENTATION TIMES FOR VARIOUS STRATEGIES, MONTHS

STRATEGY 0:		
	Training	12
STRATEGY 1:		
(a)	Negotiation of small aircraft contracts	4
(b)	Large Fixed Wing contracts	6
(c)	Dispersant acquisition by contractors	1
(d)	Dispersant stockpile (manufacturer's)	0
(e)	Exercise/Training	12
	Net Time (a) + (e)	16
STRATEGY 1A:		
(a)	Negotiation of small aircraft contracts	4
(b)	Large Fixed Wing contracts	6
(c)	Dispersant acquisition by USCG	6
(d)	Dispersant stockpile (manufacturer)	0
(e)	Exercise/Training	12
	Net Time (c) + (e)	18
STRATEGY 2:		
(a)	Negotiation of small aircraft contracts	4
(b)	Large Fixed Wing contract	6
(c)	Dispersant acquisition by contractors	1
(d)	Dispersant acquisition by USCG	6
(e)	Semitrailer acquisition by USCG	12
(f)	Dispersant stockpile (manufacturer)	0
(g)	Exercises/Training	12
	Net time, (e) + (g)	24

TABLE 22. IMPLEMENTATION TIMES FOR VARIOUS STRATEGIES, MONTHS (CONTINUED)

STRATEGY 2A:		
(a)	Negotiation of small aircraft contracts	4
(b)	Large Fixed Wing contract	6
(c)	Dispersant acquisition by contractors	1
(d)	Dispersant acquisition by USCG	6
(e)	Semitrailer acquisition by USCG	12
(f)	Dispersant stockpiles (manufacturer)	0
(g)	Exercises/Training	8
	Net Time, (e) + (g)	20
STRATEGY 3:		
Same times as Strategy 2, plus:		
(h)	Contract and acquisition of USCG stockpile (1000 tons)	12
(j)	Retainer contract for DC4	8
	Net Time, (e) + (g)	20
STRATEGY 3A:		
Same times as Strategy 2A, plus:		
(h)	Contract and acquisition of USCG stockpile	12
(j)	Retainer contract for DC4	8
	Net Time, (e) + (g)	20
STRATEGY 4:		
Same as Strategy 2		20

CONCLUSIONS

The major conclusions to be drawn from the preceding sections are

1. The most effective vehicles for dispersant application, from both a cost and application rate view, are large and small fixed wing aircraft and helicopters. Their various regimes are shown in Figure 19.

2. Commercial stockpiles of dispersants for which the EPA has accepted data are about 170 tons of water-based, 45 tons of hydrocarbon-based, and 170 tons of concentrate. Production capability is about 167 tons/day of water-based, 48 tons/day of hydrocarbon, and 110 tons per day of concentrate (Tables 10 and 11).

3. Storage characteristic data submitted to the EPA are not detailed enough for logistics planning. Relevant effectiveness data generally are not available for the 13 dispersants with data accepted by the EPA. Partial effectiveness data are available for three of the 13.

4. Eight operational strategies were analyzed: initial and annual costs run from $0K and $275K per year to $9,260K and $564K per year. The most significant cost in most strategies is that of the dispersant stockpile (Table 21).

5. Use of USCG HH3-F helicopters with slung buckets (Strategy 2A) can provide improved response (Figure 22) compared to commercial small aircraft contracts (Strategy 1).

6. Typical costs for treating a 200K liter spill are between $20,000 and $40,000. Typical costs for treating a 20,000K liter spill are about $2,000,000.

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9. U.S. Department of Transportation, Research and Special Projects Administration, Transportation Systems Center, "Logistics-Related Properties of EPA Accepted Oil Spill Dispersants for U.S. Coast Guard Use", Project Memorandum, CG 022, April 1980.

CONVERSION FACTORS

Multiply	By	To Get
Gallons (US)	0.00378	Cubic Meters
Gallons (US)	3.785	Liters
Barrels (US)	6.668	Cubic Meters
Feet	0.3048	Meters
Inches	25.400	Millimeters
Feet/minute	0.0183	Kilometers/hour
Feet/minute	0.3049	Meters/minute
Feet/second	1.097	Kilometers/hour
Feet/second	18.283	Meters/minute
Knots	1.8532	Kilometers/hour
Square Feet	9.29×10^{-6}	Hectares
Acres	0.4047	Hectares
Square miles	2.59	Square Kilometers
Square miles	259.00	Hectares
Acres	0.004049	Square Kilometers
Gallons (US)/acre	9.353	Liters/Hectare
Cubic Meters	264.55	Gallons (US)
Liters	.264	Gallons (US)
Cubic Meters	1.50	Barrels (US)
Meters	3.281	Feet
Millimeters	.0394	Inches
Kilometers/hour	54.6	Feet/minute
Meters/minute	3.281	Feet/minute
Kilometers/hour	.912	Feet/second
Meters/minute	.055	Feet/second
Kilometers/hour	.5396	Knots
Hectares	1.076×10^{5}	Square Feet
Hectares	2.471	Acres
Square Kilometers	2.59	Square Miles
Hectares	259.00	Square Miles

Square Kilometers	246.97	Acres
Liters/Hectare	.107	Gallons (US)/acre
Feet/minute	0.0114	Miles/hour
Feet/second	0.682	Miles/hour
Square miles	640.	Acres
Acres	43,560.	Square Feet
Nautical miles	6080.	Feet

APPENDIX I

ADAPTATION OF SAR PATTERNS TO DISPERSANT APPLICATION

Reference "National Search and Rescue Manual," CG-308
and Amendments Am-1, Am-2, Am-3.

Despite substantial differences between Search and Rescue (SAR) and oil spill dispersant application, the SAR patterns of the reference can be adapted in part to dispersant application. The intent in both mission types is to cover as much area in as short a time as possible. The basic SAR relationship

$$A = VSNT$$

applies to both missions,

where A = area covered

V = vehicle speed in search or spray

N = number of vehicles

S = track spacing, swath width

T = time in search or spray.

The following comments are intended to guide the adaptation of the 33 SAR patterns of the Reference to oil dispersant application.

1. Trackline Patterns (TSR, TMR, TSN, TMN)

These patterns are oriented along the intended track of the target. They are adaptable to vessel application of dispersant when the slicks are elongated. They are not well adapted to aircraft application if there is a wind and if the slick is not aligned with the wind. Another difficulty in use by aircraft is that the ratio of sweep width/turning radius is much smaller for dispersant application than for SAR. This has two effects:

(2) Aircraft spacing would have to be too tight to allow use of the multiunit patterns TMR and TMN, without extremely tight aircraft-aircraft coordination.

(2) The single-unit patterns TSC and TSN would require large turn circles, relative to sweep width, at each end of the pattern. This results in an inefficiency. The inefficiency, however, is inherent in the use of aircraft for an elongated slick pattern.

The Parallel Trackline patterns of SAR have been adapted as patterns #3 and #5 in Figure 2 of the report.

2. <u>Parallel Patterns</u> (PS, PM, PMR, PMN, PSL, PSA, PSC, PMC, PSS)

The PS pattern is practical for vessels but becomes inefficient for aircraft for the reasons above. It is shown in Figure 2, pattern #5 in the report. The PM patterns PMR and PMN are also unsuited to aircraft, for the same reason, but can be used profitably by vessel spray systems.

The parallel patterns PSL, PSA, PSC are not applicable to dispersant application since navigation referenced to a radio aid is never more practical for dispersing oil than navigation relative to the oil slick itself. This is also true at night and in low visibility weather conditions, when dispersal operations are not practical at all.

The parallel patterns PMC and PSS are keyed to the use of lines which may be practical for vessels but not for aircraft. The PSS pattern, without the line, is adopted to dispersant use in Figure 2, pattern #4 of the report.

3. <u>Creeping Line Patterns</u> (CS, CM, CMC, CSC, CMR, CMCS)

The CS and CM patterns are of little use for vessels, since the elongated patterns PS and PM are usually more efficient, involving fewer turns. The CS-type pattern is of use by aircraft when the wind is normal to the slick axis, but even in that condition it may still be advisable to apply dispersant parallel to the slick if it's an extremely elongated slick, allowing an offset for the cross-wind. The radar version CSR is not relevant to dispersant application.

CM is to difficult for aircraft to execute safely in dispersal of oil. The coordinated patterns, in which a vessel coordinates aircraft movement, are not of use in dispersant application, since the slick is more visible form the air than from the vessel.

4. Square Pattern (SS,SM)

The single-vehicle square pattern SS cannot be executed for dispersion by fixed wing aircraft and is difficult for helicopters. It is more practical for vessels. But a contracting square pattern, i.e., one in which the vehicle spirals in to the center, is also suited to dispersant application by a single vehicle because (a) the time for a circuit, at least initially, is greater and this allows more time for the dispersant to have an effect, making it easier to lay successive tracks accurately, i.e., to avoid overlapping; and (b) it works from the edge of the slick inward, thus inhibiting its spread.

Variations of the SM pattern can be devised that are suitable for vessels, but not for aircraft.

5. Sector Patterns (VS, VM, VSR, VMR)

These patterns are not only less efficient, but when used for oil dispersal can result is heavy overdoses at the center. They should be avoided for that reason. Further, they are not suitable for aircraft application in a wind, because of the continually changing headings.

The most likely circumstances in which the Sector Patterns may be usefull in dispersant application is that of one or more vessels with adjustable rate pumping systems operating in an area in which parallel, square, or creeping line patterns are not possible.

The radar-controlled patterns VSR and VMR offer no advantage for dispersant application, and in fact, are substantially useless for that purpose because of the limited radar accuracy.

6. <u>Contour, Flare, and Houring Patterns</u>

These patterns are inapplicable to dispersant application.

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